

## Review

## Closer to reality: Reconstructing total removals in mixed fisheries from Southern Europe



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## ABSTRACT

Underestimation of catches is especially important in countries where fishing fleets are highly diversified, the enforcement of fishery management is low, data availability is poor, and there is high demand for fish products in local markets. This is the case for southern European and Mediterranean regions. Adapting a catch-reconstruction approach, we estimated the total removals of marine resources by Spain for the Spanish Mediterranean Sea and Gulf of Cadiz regions from 1950 to 2010. We collected available information from scientific publications, the grey literature and secondary sources of information to complement officially reported catch data. We assessed missing catch sectors as time-point estimates, used as anchor points of reliable data upon which we then estimated total catch using interpolation to fill in the periods for which quantitative data were missing. Unreported removals and discards represented important portions of total removals in the study area. They accounted for, on average, 43% of total removals between 1950s and 2010, and were composed of black market sales, subsistence fishing, artisanal fishing, recreational fishing and illegal catch, in addition to discarding. By the late 2000s, recreational fishing was the most important sector for unreported landings (~36%), followed by black market sales (~32%), subsistence fishing (~17%), unreported artisanal fishing (~12%) and illegal catch (~2%). The overall catch trend differed from the official trend highlighting that the depletion of marine resources in the region started earlier than previously observed. The catch composition changed with time, with a higher diversification of species in fish markets with time. These results indicate an earlier trend towards expansion of fisheries and depletion of marine resources.

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## 1. Introduction

Fishing is an important human activity shaping marine ecosystems (Costello et al., 2010; Pauly et al., 2002), and exploited marine resources are of concern worldwide (Christensen et al., 2003; Coll et al., 2008; Froese and Proelß, 2010). Several national and international initiatives aim to halt degradation trends and ensure the sustainability of fisheries, such as the European Community new common fisheries policy (CFP) and the Marine Strategy Framework Directive (MSFD), and the Code of Conduct for Responsible Fisheries of the food and agriculture organization (FAO) of the United Nations (UN) (EC, 2008; European Community, 2002; FAO, 1995).

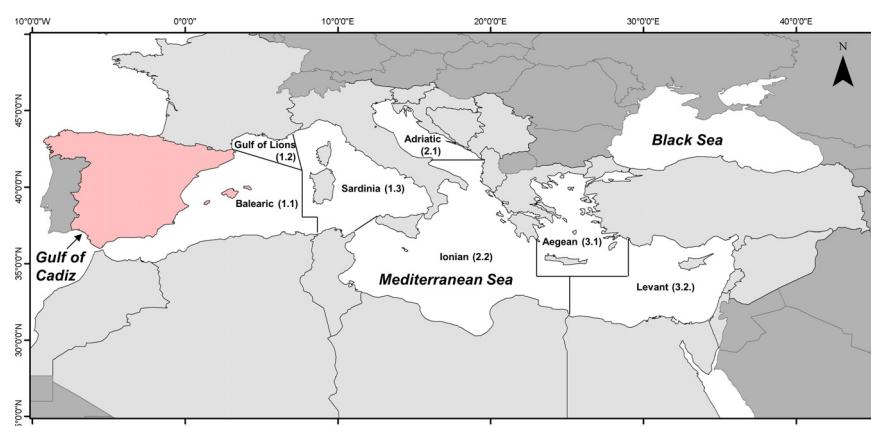
The world's officially reported catches increased from the 1950s to the early 1990s and fluctuated from then until the present (FAO, 2010). However, it is now well recognized that officially reported catches are frequently underestimated (Zeller and Pauly, 2007) due to illegal, unreported or unregulated (IUU) catches (Agnew et al., 2009; Bray, 2000; Evans, 2000; FAO, 2002; Pitcher et al., 2002). Underreporting is caused, among other things, by unaccounted discarding practices (Kelleher, 2005), recreational fishing (Coleman et al., 2004), illegal catch (e.g., Atlantic bluefin tuna, ATRT, 2006), as well as smaller-scale fisheries, which frequently are not taken into account in the overall assessment of fisheries removals. IUU catches complicate or even defeat the development of suitable management actions. They also lead to underestimation of the contribution of fisheries to the gross national product, while having costs associated with control and inspection. IUU catches can also have social impacts due to competition with legal activities, and especially with artisanal fishing.

The Mediterranean Sea (Fig. 1) is a hotspot of biodiversity, and hosts approximately 7–10% of the world's marine biodiversity with high percentages of endemic species (Bianchi and Morri, 2000; Coll et al., 2010). At present, fishing impacts, as well as habitat loss

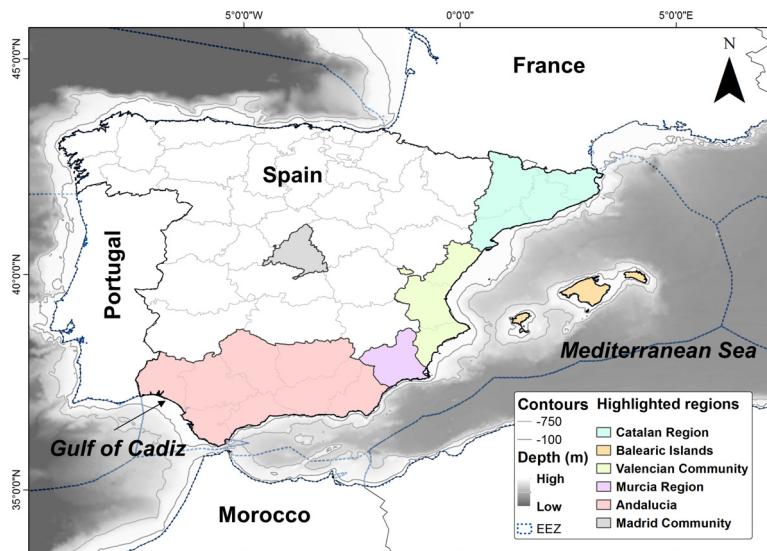
and degradation, pollution, eutrophication, and the introduction of alien species are the most important threats to its diversity (Coll et al., 2012, 2010; Costello et al., 2010).

Official Mediterranean landings have steadily increased from the 1950s to the 1980s, decreased in the 1990s and have fluctuated since then. The most important countries fishing in the area are Italy, Spain, Greece, Turkey, Tunisia and Egypt (FAO, 2011b; Sea Around Us Project, 2011). Scientific and management advice in the Mediterranean Sea is implemented by national and regional entities, in addition to several international organisations, such as the General Fisheries Commission for the Mediterranean (GFCM), in cooperation with the Fisheries Department of the United Nations Food and Agriculture Organisation (FAO), and the European Community (EC), the International Commission for the Conservation of Atlantic Tunas (ICCAT) and the United Nations Environmental Program (UNEP). All the EU Member States have to collect fisheries data following the Data Collection Framework (DCF), with the main objective to provide the basic data needed to evaluate the state of fishery resources and the fisheries sector to support scientific advice regarding the Common Fisheries Policy (CFP) of the EU.

Despite many stakeholders being involved in fisheries monitoring and management, evidence of substantial unreported landings and failures of the control system is available for many European and Mediterranean countries (Mora et al., 2009), including Spain. In 2007, a special report by the European Court of Auditors highlighted many deficiencies and failures of control, inspection and sanction systems of six European countries, including Spain (Court of Auditors, 2007). The Court stated that overfishing generated by overcapacity, and the considerable weaknesses of the European fisheries control system are threatening European fish stocks. The Court concluded that (i) fishing data collected in Member States of the European Union are unreliable and incomplete, and are



**Fig. 1.** The Mediterranean Sea, the Gulf of Cadiz, and FAO fishing areas.



**Fig. 2.** The Spanish Mediterranean Sea and Gulf of Cadiz regions. Waters under each country jurisdiction are highlighted.

inadequate as a basis for setting Total Allowable Catches (TACs) and quotas; (ii) national inspection procedures to detect and prevent infringements are ineffective; and (iii) the penalties imposed by national authorities when infringements are detected are not sufficiently onerous to act as a deterrent. Spain was highlighted as a frequent offender due to, for example, extensive underreporting of catches of large pelagic fish.

Although FAO and other organizations recognize the importance of IUU practices (FAO, 2002), and European countries have officially committed themselves to estimate and control IUU catches (MAPA, 2007), local and regional fisheries experts, government employees, and fishers are aware of the limited nature of official fisheries data and of the large amount of unreported catches. Administrations in charge of collecting the data rarely show the will to quantify these missing catches. Therefore, estimates of IUU in the region are still very scarce, with preliminary data only available for Greece (Tsikliras et al., 2007), Corsica (Le Manach et al., 2011), Turkey (Ulman et al., 2013), and the Balearic Islands (Carreras et al., 2013).

In this study, we contribute to the global effort to estimate the world's total fisheries removals by estimating the total removals of marine resources for 1950–2010 by Spain from the Spanish Mediterranean Sea and Gulf of Cadiz regions. Both regions share similar ecological and socio-economic traits.

To estimate total fisheries removals, we adapted the catch-reconstruction approach developed by Zeller and Pauly (2007). We collected information from scientific publications, the grey literature and secondary sources of information to complement official catch data, which are publicly available from FAO databases and

from national and regional statistics. We assessed missing sectors (i.e., discards, recreational fishing, and black market sales) that are time-point estimates. They were used as anchor points of reliable data upon which we then estimated total catch using interpolation to fill in the periods for which quantitative data were missing. When data were not available or had limitations, we documented those.

## 2. Material and methods

### 2.1. The Spanish Mediterranean Sea and Gulf of Cadiz regions

Our study area spans the Spanish Mediterranean Sea and the Gulf of Cadiz regions (Fig. 2). This region is located in the Balearic FAO area 37.1.1 and the South-East Atlantic area 27.IXa (Fig. 1). It includes five Autonomous Regions (AR) with seventeen provinces (PR), and hosts approximately 24 million people (Table 1; Fig. 2).

The Spanish fleets in the area mainly fish in FAO area 37.1.1, the Balearic region, and in the South-East Atlantic FAO area 27.IXa, in the Spanish Gulf of Cadiz (Fig. 1). Data from FAO show that the official Spanish landings from the Mediterranean Sea are originating mainly from the Balearic region, since they are very similar to total Spanish Mediterranean catches in the FAO dataset. The continental shelf in the Spanish Mediterranean and Gulf of Cadiz regions is generally narrow, and the 50 m depth is usually found approximately 3 nm from shore, with the exception of the Gulf of Cadiz where the continental platform is wider (Fig. 2). Fishing activities are mainly coastal, and last on average 12 h. The main fishing fleets operating in

**Table 1**

Population and fisheries related information by Autonomous regions of the study area (sources: Franquesa et al., 2004; JA 2011; MAPA 2007; MARM 2011).

Autonomous Regions	Population (2010)	No. harbours	No. Cofradías	No. Lonjas	No. vessels	Power (Kw)	Total Gross Tonnage	Vessel mean Length (m)	Nº Professional fishers
Catalonia	7,504,881	29	29	19	1040	128,449	27,267	13	4500
Balearic islands	1,106,049	16	16	2	432	24,111	3,931	9	770
Valencia community	5,111,706	23	23	17	697	104,695	28,028	15	760
Region of Murcia	1,424,063	4	4	5	221	17,108	4,224	11	480
Andalusia	8,370,975	23	23	25	1750	179,230	63,020	12	6745 <sup>a</sup>
Total	23,517,674	95	95	73	4140	453,593	126,470	12	13255

<sup>a</sup> 2010 Junta de Andalucía.

**Table 2**

Number of boats by fleet from the Spanish Mediterranean Sea and Gulf of Cadiz regions in 2006 (source: MAPA, 2007).

No. of boats	Bottom trawls	Purse seiners	Long liners	Tuna fleet	Artisanal fleet
Spanish Mediterranean	971	334	133	6 seiners, <i>Almadrabas</i> , and artisanal fleet	2577
Spanish Gulf of Cadiz	215	113	–	–	527
Total	24.3%	9.2%	2.7%	0.1%	63.7%

the area are bottom trawling (~24% of the fleet), purse seine (~9%), bottom and surface long lines (~3%), and a diverse artisanal fleet (~64%) (Table 2). The area contains 95 fishing harbours, >90 first-source fishing markets (or *Lonjas*, where catches that are unloaded in the harbour are first sold), and several fishers' labour organizations or "*Cofradías de pescadores*", which are unique to Spain and date back to early Medieval times (Álvarez Ereipa, 2008) (Table 1). In 2008–2009, the total number of vessels in the study region was 4140, with total declared power of 453,593 Kw and a mean total length of 12 m (MARM, 2011) (Table 1). In the late 2000s, more than 13,000 people directly worked as fishers in the area (Table 1).

Several governmental and inter-governmental institutions at different hierarchical levels (European community, national, regional and local scale) are involved in the legislation, management and/or control of fishing activities in the study area, such as the EC, ICCAT, the Spanish ministry of Environment, and rural and marine areas (MARM), the AR through regional government bodies, the municipalities, and the *Cofradías*. The legislation regarding the management of marine resources in the Mediterranean Sea is generally based on the direct control of fishing effort. This system is based on general rules, such as the definition of selectivity and other technical measures by fleet, the limitation of number of days per week and hours per day that fishing is allowed and limitation of engine power, the establishment of minimum legal sizes for main commercial species, and the prohibition of trawling and purse seining in coastal areas (MAPA, 2007; Romberg and Sardà, 2005). Temporal closures also exist. Indirect measures to control fishing effort only exist for bluefin tuna, which is the only species that is regulated using a Total Allowable Catch (TAC).

National legislation applies to the Spanish fleet within the national jurisdiction (12 nm territorial sea), the exclusive economic zone beyond territorial waters (EEZ) and the zone of protection for the Mediterranean Sea (ZPP), and in theory, it is more restrictive than EC regulations. The AR manages fishing activities in the coastal region, in addition to shellfish and aquaculture activities. Moreover, AR governments establish temporal limits on the maximum catch of specific species by fleet during certain periods of time to protect the resources. The self-organizing *Cofradías* also play a key role in the management and control of fishing activities in coastal waters since they employ a system of 'territorial use rights in fisheries' (TURF) (Franquesa, 2005). Other measures to limit fishing effort are the establishment of marine protected areas and artificial reefs.

The marketing of the catch obtained from the study area involves several institutions (Alegret, 2005). Approximately 70% of all fresh catches are directly sold in the *Lonjas* to central markets and the exporting industries, while 30% is directly sold from vessels or through other markets authorised by AR, but they have to be registered in *Lonja* statistics (MAPA, 2007). *Cofradías* benefit from these markets which promote benefits for fishers and, although it is not compulsory to sell the product in *Lonja*, in many *Cofradías* it is socially reinforced (Franquesa, 2005). The central markets distribute fresh products to local markets. In the *Lonjas*, fishers' organizations, cooperatives and associations of ship-owners and traders are the ones organizing the marketing of landings (through auctioning) to central markets and exporters, and they are also in charge of registering total landings.

## 2.2. Catch-reconstruction approach

To estimate total fisheries removals from our study area, we adapted the catch-reconstruction approach documented by Zeller and Pauly (2007) and Zeller et al. (2011), and consisted of six main steps:

- (i) Collection of time series of available reported landings from regional (i.e., Autonomous regions and *Cofradías*), national (MARM and other government bodies) and international (i.e., FAO and ICCAT) agencies;
- (ii) Identification of those fisheries sectors and components that currently produced or could have produced unreported removals using literature searches and secondary data sources;
- (iii) Search for available alternative information regarding those sectors and components that produced unreported removals;
- (iv) Collection of alternative estimates and development of anchor points in time for missing data;
- (v) Interpolation between anchor points for time periods to estimate the different components of unreported removals;
- (vi) Estimation of total fisheries removal time series as the sum of total reported landings and unreported removals.

For each year, we defined total fisheries removals (TR) as the sum of total fisheries landings (TL) and total discards (TD) for *S* caught species and *F* fishing fleets as following:

$$TR_{S,F} = \sum_{S=1,F=1}^{S,N} (TL_{S,F} + TD_{S,F}) \quad (1)$$

TL for *S* caught species and *F* number of fishing fleets was composed by the following elements:

$$TL_{S,F} = \sum_{S=1,F=1}^{S,N} (OL_{S,F} + UL_{S,F}) = \sum_{S=1,F=1}^{S,N} (OL_{S,F} + BM_{S,F} + IC_{S,F} + AC_{S,F} + RC_{S,F} + SF_{S,F}) \quad (2)$$

where OL is official landings and UL is unreported landings. UL is composed of unreported legal catches that go to black market sales (BM), or the proportion of the total catch that, although legally captured, goes into the black market, and illegally caught species (IC), which is the proportion of the non-reported catch that is illegal due to being protected species, of illegal size or caught using illegal fishing gear. It also includes artisanal catch (AC) and recreational catch (RC) not reported in official landings, and subsistence fishing (SF), or the personal consumption of fishing products by fishers and their families.

TD for *S* species and *F* fishing fleets are composed of the following elements:

$$TD_{S,F} = \sum_{S=1,F=1}^{S,N} (D_{S,F} + PM_{S,F} + GF_{S,F}) \quad (3)$$

where *D* is direct boat-based discards from fishing activities (Kelleher 2005), PM is post-escapement mortality, or underwater

discards, of those specimens that die after escaping from fishing nets due to physical damages (Suuronen, 2005), and GF is ghost fishing mortality of those specimens that die due to lost or abandoned gear or the loss of fishing gear at sea (Brown et al., 2005a; Macfadyen et al., 2009).

We considered as unreported removals, or IUU catch, all the elements of TR that are not included in OL and discards. To calculate TR, we collected and compiled all material available: from primary literature and official sites, final projects report, grey literature, statistics from regional institutions, estimates from experts, observations in harbour areas and markets, and opinions of local fishers and fisheries experts collected through interviews. We collected the data in terms of total fisheries removals by fleet and by single species, directing particular effort towards those species that are known to contribute the most to the catch: small pelagic fish, and commercial demersal fish. Special attention was also paid to highly commercial invertebrate species. We used historical clues to understand if underreporting may have happened in the past, and if it may have been larger or lower than at present.

### 2.3. Data sources

Data available to the study were sometimes accessible by ocean (Atlantic Ocean and Mediterranean Sea) or by Autonomous Region (AR). In the latter case, we distinguish the Andalusia Mediterranean region and the Andalusia Gulf of Cadiz region, in the South Atlantic, since the Andalusia Autonomous region has coastlines both along the Atlantic Ocean and the Mediterranean Sea (Fig. 2).

In the supplementary material (Annex 1, and its Tables S1–S3) all information about the data sources is detailed. Data sources were divided between official landings, including FAO capture production data, ICCAT data, national statistics, and regional statistics, and unreported data and discards.

#### 2.3.1. Official landings

Regarding official landings, we used the capture production data available from the Spanish Mediterranean Sea and Gulf of Cadiz areas in the online FAO FishStat capture production database to obtain baseline officially reported catches (Table S1, supplementary material and Annex 1). Two databases were used: (1) Global dataset of capture production 1950–2009 (extracted February 2011), and (2) Regional dataset of GFCM (Mediterranean and Black Sea) capture production 1970–2008 (extracted December 2010) (FAO 2011a,b).

We included information from ICCAT regarding official data reported by Spain from the Mediterranean Sea for bluefin tuna landings and related species such as albacore tuna *Thunnus alalunga*, bonito *Sarda sarda*, bullet tuna *Auxis rochei*, frigate tuna *A. thazard*, little tunny *Euthynnus alletteratus*, and skipjack tuna *Katsuwonus pelamis* (<http://www.iccat.int/en/t1.asp>, Task I) (Table S1, supplementary material and Annex 1). Time series of official landings of pelagic sharks from Spanish waters were also obtained from the ICCAT Task I dataset.

Different datasets were consulted to reconstruct official landings data from National Statistics and were compared with FAO datasets (Table S1, supplementary material and Annex 1). We also included tuna species data from the *Almadrabas*, or fixed tuna traps, which are an old fishing technique of setting nets in a maze that leads to a central pool that is used to capture large pelagic fish in the Mediterranean Sea.

From these datasets, we chose the years 1950, 1960, 1970, 1980, 1990, 2000, and 2008 as anchor points and data by detailed species and region were recovered. Data gaps were identified from 1987 to 1995, since official data from the Central Government was not available. Thus, to complement the time series, we used a linear extrapolation using 1986 and 1996 as anchor points.

Official available data from the Autonomous governments of Catalonia, Valencia Region, Murcia Region, Andalusia, and Balearic Islands were obtained from regional administrations. The available datasets, combined with national statistics covered most of the study period from 1950 to the late 2000s (Table S1, supplementary material and Annex 1).

#### 2.3.2. Unreported landings

We carried out a literature research and a series of interviews to fishers and government employees. This information provided anchor points from where we estimated unreported catches. When historical information was available we took that into account, otherwise we extrapolated from intermediate periods of time with available data.

Our literature review was used to identify hot topics where unreported landings occur, such as (i) illegal catch (e.g. bluefin tuna overfishing), (ii) illegal fishing techniques (e.g., the Spanish drift-net fishery after the 1992 ban), and (iii) portions of misreported legal catch (e.g., sharks catch) or (iv) catch not reported in the official statistics, as it is mainly the case for recreational fishing (Table S2, supplementary material). This information was used to estimate unreported catches by region and main species for time periods available. Time series of official landings of pelagic sharks from Spanish waters that were obtained from ICCAT dataset of task I were complemented with incidental catch reported for sharks (Megalofonou et al., 2005).

A series of interviews with fishers were carried out during 2009–2011 in ports of all the study area, both in the Spanish Mediterranean and Gulf of Cadiz regions, and had three main objectives: (i) verify the existence of unreported catches and identify principal sources of non-reporting, (ii) quantify, by fishing fleet and target species, the unreported catch, and how this unreported catch may have changed over time, and (iii) collect additional information on discarding as the interviews were part of a larger study to collect information on historical and current knowledge of Mediterranean ecosystems and fishing activities using fishers' perceptions (Coll et al., 2014). In our study area, the catch by the artisanal fishery was mainly registered in the *Lonjas*, although artisanal fishers can use other marketing mechanisms (Alarcón Urbistondo, 2002). Using the fishers' interviews, we also quantified the amount of artisanal catch that is not officially reported.

In addition, within the umbrella of the data collection framework (EC regulation 199/2008), concerning the establishment of a community framework for the collection, management and use of data in the fisheries sector and support for scientific advice regarding the Common Fisheries Policy, carried out by the Instituto Español de Oceanografía (IEO), data from the Spanish National Data Collection Program were used to compare landing declarations and sales notes (Carreras et al., 2013; Torres, 2013). We cross-checked this information and quantified the proportion of the landed catch from trawling that was not declared in the sales notes during 2008 and 2009; thus, it was not included in the official landing statistics.

#### 2.3.3. Discards

Data regarding discards in the study area were collected from available literature and from interviews with fishers (Table S3, supplementary material, and Annex 1). This information provided anchor points used to estimate the rest of catches (Table 3). When historical information was available, we took that into account; otherwise we extrapolated from intermediate periods of time with available data. Combining available information from the literature by region (first by area and then by year) and results from the fishers' interviews (by region in late 2000s), we estimated a possible percentage of discarded catch for the major caught species and fishing fleet by region of the study area.

**Table 3**

Anchor points or historic and anecdotal clues to develop the reconstruction of total fisheries removals.

Anchor points	Historic or anecdotal clues	Source
Before 1950 1950s	Hardy any catch was declared to the government Catch was not weighted, data is only indicative. But everything was used (very little discarding) and quantities were low	Fishermen interviews and C. Bas pers. comm. C. Bas pers. comm.
1950–1960	Trawl fishing was very small. Although there was lots of discarding of small fish, including mackerel and horse mackerel, bogue, <i>Spicara</i> sp. and blue whiting	C. Bas pers. comm.
1960s	Fishing activity from Cadiz harbor in Mauritania started during the 1960s and continues today in low quantities	I. Sobrino pers. obs.
End of 1960s	The catch started to be weighted when landed.	C. Bas pers. comm.
Mid 1960s to 1990s	Large development of fishing capacity and fishing economic incentives	C. Bas and F. Sarda pers. comm.
Mid 1980s	The use of driftnets in the Alboran Sea started in the 1980s	(Silvani et al., 1999; Tudela et al., 2005)
1992	Driftnets were banned. However, this activity continued until 1994 in Spanish waters.	(Silvani et al., 1999)
1996	Large amounts of by-catch of sunfish and other pelagic organisms were reported	
1999	Fishing activity in Morocco, whose catches were landed in the Spanish Gulf of Cadiz and started at the end of the XIX century, finished in 1996	(Sobrino et al., 1994)
Spain and Gibraltar signed an agreement so Spanish fishing vessels (4 at a time) could fish in the English area, operating at a distance of 250 meters from the coast minimum. This regularized a "de facto" situation		
Early 2000 1990–2000s	Official data were more reliable Availability of studies reporting discarding in the study area Availability of studies characterizing the importance of recreational fisheries	J. Rodon pers. comm. Table S3 supplementary material Table S2 supplementary material (Hareide et al., 2007; Macías et al., 2004; Megalofonou et al., 2005; Silvani et al., 1999) (ATRT, 2006; ATRT, 2010; Mielgo Bregazzi, 2011 Raymakers and Lynham, 1999) (Court of Auditors, 2007)
1990–2000s	Incidental catch reported for large pelagic sharks from fishing activities targeting tuna and swordfish	
1998–2010	Atlantic bluefin tuna was highly unreported in official statistics	
2007	A special report by the European Court of Auditors highlighted many deficiencies and failures of control, inspection and sanction systems of 6 European countries, including Spain	
2000s–2010	Spain was the second largest exporter of shark fins to the Hong Kong market after China and shark finning was profitable activity	(Hareide et al., 2007; Lack and Sant, 2011; OCEANA, 2008)
2008–2009	The IEO conducted comparisons of landing declarations and sale notes to cross-checked declared information and quantified the proportion of landed catch not declared in the sales	(Torres, 2013)
2008–2010	Economic crisis: black market was highlighted in the media as very important in Spanish harbors	
2008 onwards	Direct selling of catch to tourists and visitors was frequent in several harbors	E. Morote and M. Coll pers. obs.
Through the years	Due to low prices, sardines and anchovies went off board frequently	C. Bas and A. Rillo pers. comm.

### 3. Results

#### 3.1. Different components of total fisheries removals

##### 3.1.1. Official landings: FAO databases and national and regional statistics

Both FAO datasets (the global dataset from 1950 to 2009 and the GFCM dataset from 1970 to 2008) showed similar official landings by Spain from the Mediterranean area 37 (Fig. 3a). However, this was substantially lower than the official national dataset, especially from 1961 to 1985 (Fig. 3a). Official landings available from the Spanish Gulf of Cadiz area of the South Atlantic FAO area 27 from FAO global dataset from 1950 to 2009 were also lower than national data available (Fig. 3b).

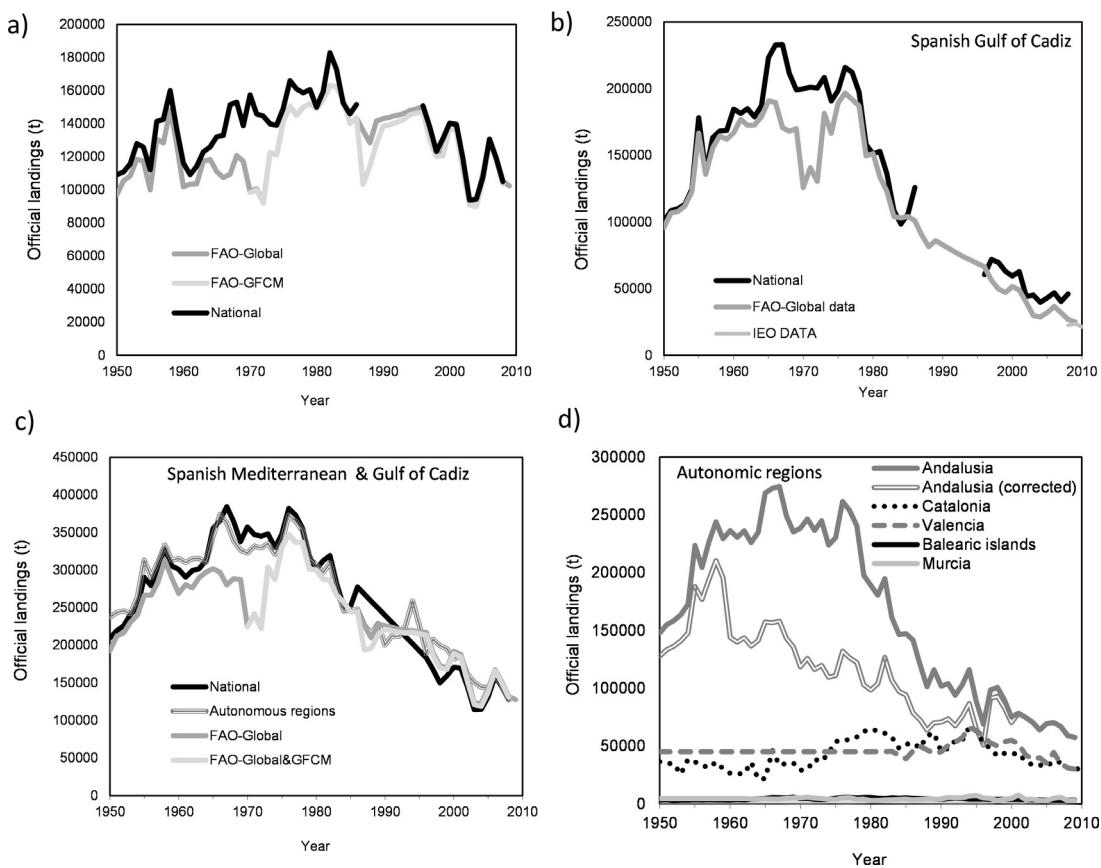
The combination of data from both Spanish areas (Mediterranean and South Atlantic) using various sources also documented data discrepancies (Fig. 3c). We observed a general increase of official landings in the Spanish Mediterranean and Gulf of Cadiz regions from 1950 (approximately 200,000 t year<sup>-1</sup>) to the late 1960s (with a maximum of 374,162 t year<sup>-1</sup>) and a decline from the 1970s to 2008 (to 130,000 t year<sup>-1</sup>). When comparing data from national statistics and autonomous region statistics (Fig. 3d), we noticed that catches by region were slightly lower than in national statistics during the 1960s and 1970s, but were higher from the 1990s onwards (Fig. 3c). This may suggest changes in the mechanisms of reporting landings from regional to national administrations.

Andalusia was the region that officially registered most landings, even after official data had been corrected to take into account landings that were caught outside Spanish waters, in Morocco and Mauritania (Fig. 3d). The Catalan and Valencia regions followed with similar amounts.

Combining data from the *Almadrabas* or fixed tuna traps (from historical official landings data from 1950 to 1986) with data from ICCAT including declared Spanish catches of tuna-like species and swordfish (*Xiphias gladius*), we reconstructed the minimum official landings of these large pelagic fish from the study area (Fig. 4a). In 1943, *Almadrabas* generated a total of 13,000 t year<sup>-1</sup>, but this amount declined to 1400 t year<sup>-1</sup> by 2000. ICCAT data started in 1950 with a reported 1,850 t year<sup>-1</sup>, which increased to 3700 t year<sup>-1</sup> in 2009. ICCAT data on by-catch species of sharks were non-existent for most of the time period analysed (Fig. 4b). Jointly, i.e., combining the *Almadrabas* and information from ICCAT for tuna-like species, swordfish and pelagic sharks showed a global decline of catches from 1950 to the late 1960s, with current catches fluctuating around 4000 t year<sup>-1</sup> (Fig. 4a).

Comparing the original national or regional data with corrected data to take into account catches from foreign waters by the Andalusia region and catches of large pelagic fish, we found that a decreasing trend of official landings from 1960 to 2008 emerged (Fig. 5a). The duration of the official increase was reduced to the 1960s, since it was mainly due to catches originating from African fishing grounds and landed in Andalusia.

Official landings of main species caught in different years showed changes in species composition over time (Fig. 6). Sardine (*Sardina pilchardus*), hake (*Merluccius merluccius*) and anchovy (*Engraulis encrasicolus*) were the main species caught during the study period, but their catch declined over time. Horse mackerel (*Trachurus* spp.) fluctuated, and mackerel (*Scomber* spp.) showed an increase. Official landings of elasmobranchs clearly declined from the 1950s to the 1970s, while round sardinella (*Sardinella aurita*), octopuses, and blue whiting (*Micromesistius poutassou*) increased substantially. The striped venus clam (*Chamelea gallina*) was very



**Fig. 3.** Official landings (t) from (a) Spanish Mediterranean area FAO 37, (b) Spanish Gulf of Cadiz area (South Atlantic FAO area 27), (c) both Spanish Mediterranean and Gulf of Cadiz regions (FAO areas 37 and partial 27), and (d) official landings by Autonomous regions (source: FAO, Spanish National Statistics and Autonomous governments, Table S1, supplementary material).

important in the 1950s and 1970s (especially in the Gulf of Cadiz region), and red shrimp (*Aristeus antennatus*) landings (mainly from the Mediterranean Sea) were especially important in the 1950s and 1980s, showing clear fluctuations. Species that contributed to less than 1% of the catch increased with time, from 20% in the 1950s to >30% in late 2000s (Fig. 6).

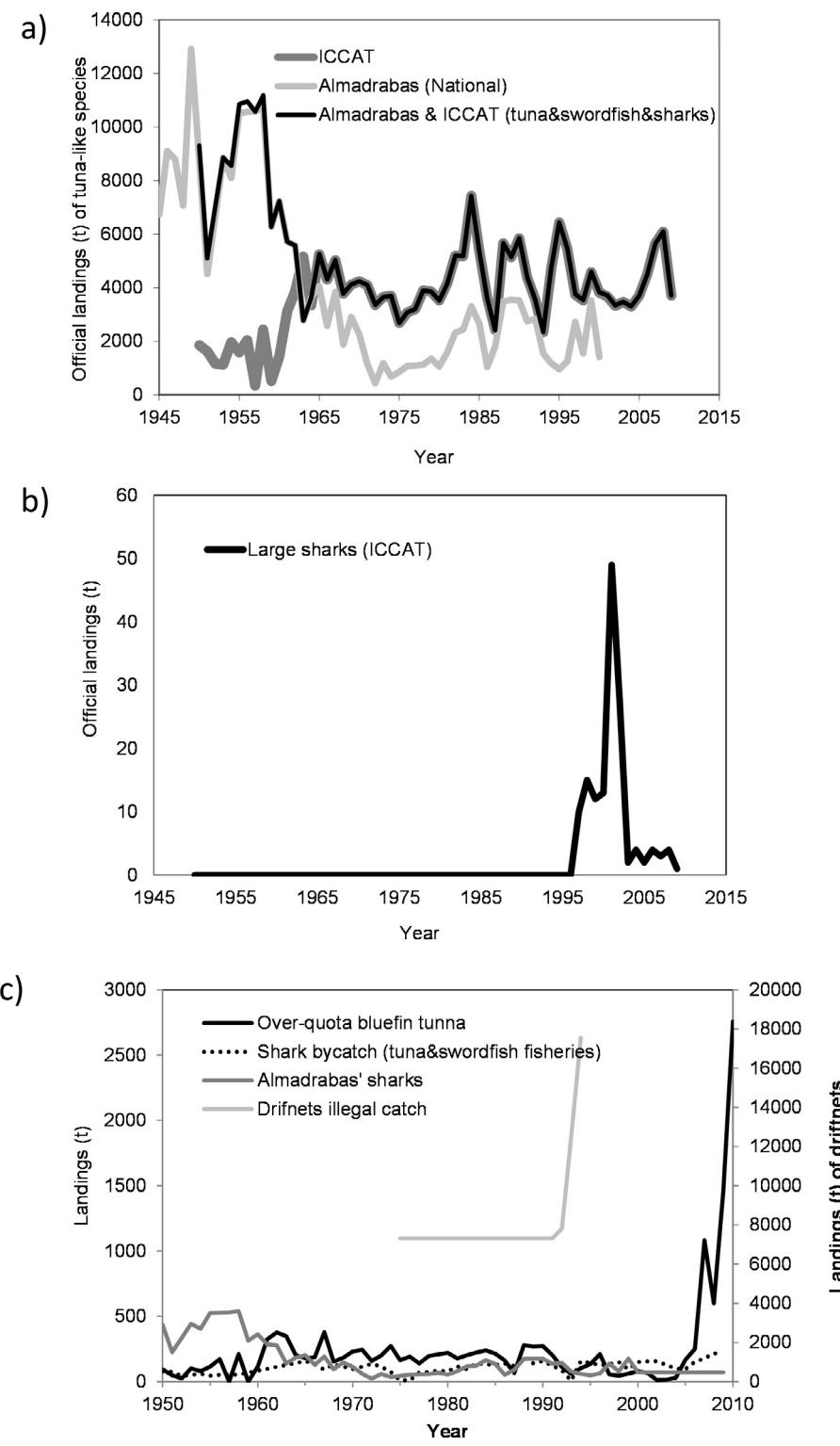
### 3.1.2. Unreported fisheries removals

We identified the key components of unreported catches, such as (i) unreported legal landings or those landings that are sold in the black market, (ii) unreported artisanal and recreational removals, (iii) unreported subsistence fishing, (iv) unreported discards, and (iv) illegal catches by Spanish fishing fleets, mainly from driftnets during the 1990s.

**3.1.2.1. The 'black market' and subsistence fishing.** Seventy-seven per cent of interviewed fishers confirmed the existence of unreported catches, while 19% denied their existence. Principal sources of non-reporting were fish that were consumed by fishers' family and relatives (54%) (the so-called 'take-home catch', treated here as a part of subsistence fishing), followed by fish that directly went to family businesses (e.g., fish shops or restaurants, 33%) and fish that were directly sold to traders (30%). Important amounts of catch were also directly sold to individuals in the harbour area (18%), while other sources of non-reporting identified were less important: such as direct sales to other local industries (7%), direct sales through the Internet (7%) and sales to central markets (4%).

According to fishers, these unreported catches added, on average, 20% of additional catch to the officially reported landings in the region, while responses from the Gulf of Cadiz recognised larger

values, closer to 50% (although less data were available from this region than for the Mediterranean area). Available data obtained from the Spanish National Data Collection Program, which is being carried out by the IEO for the Gulf of Cadiz regarding landing declarations and sale notes quantified a mean of 23.5% of catch that were caught by trawlers, but that where not declared in the *Lonjas* during 2008–2009 (Torres 2013). Results of a similar study carried out by the IEO in the Balearic Islands with observers on board trawlers during 2001–2010 highlighted that, on average, 11% of all catches are not officially recorded (Carreras et al., 2013). These independent estimates are in agreement with our estimates from trawlers (Fig. 7a). Therefore, we used this mean as representative of the area, both in the Mediterranean and the Gulf of Cadiz. Mean values of non-reporting were highest for long lining, gillnets, trawling, and purse seine (Fig. 7a). Fishers mentioned 27 species of fish and invertebrates that were unreported in different regions, including those species with important catches (Fig. 7b). Of the fishers interviewed, 41% declared that non-reporting had decreased over time since they started fishing, while 12% thought that it had increased, and 47% did not answer or said they did not know. The mean decline in unreported catches was –26% in the Mediterranean, fishers indicated a mean decline of –27%, in line with historical anchor points (Table 3). However, in the Gulf of Cadiz, fishers argued that non-reporting had increased by +2%. To account for this information in our estimate of total catch, we compared data with the assumption that non-reporting had been similar during all-time series investigated and the assumption that had declined from 1950 to 2010 by 26% (Fig. 5b). Data from fishers' interviews indicated that considerable amounts of fish were used for self-consumption by the fishers and their families (treated here as subsistence fishing) or for

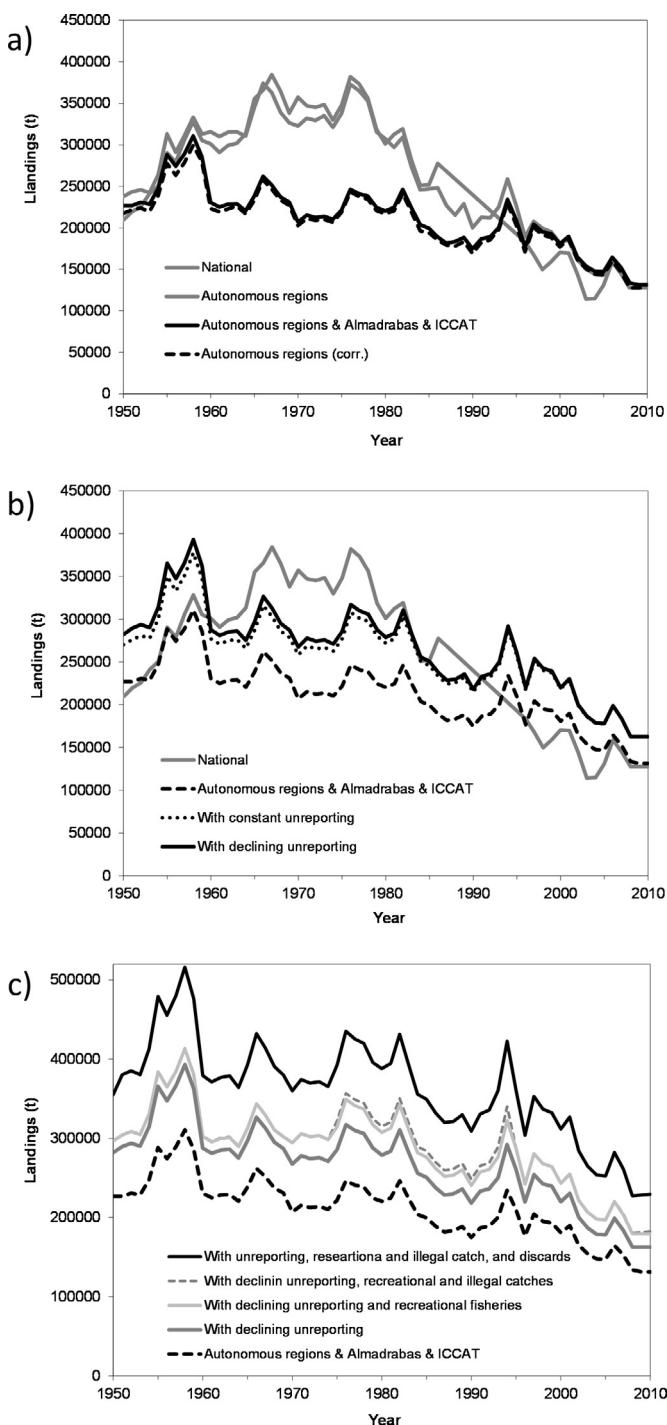


**Fig. 4.** Official landings (t) of (a) tuna-like species, (b) large pelagic sharks (source: ICCAT (Table 3)), and (c) illegal catch or non-reported catch of vulnerable species (t) (sources: ATRT, 2006; ATRT, 2010; Mielgo Bregazzi, 2011; Raymakers and Lynham, 1999; Silvani et al., 1999).

family businesses (i.e., commercial ventures). According to fishers, this was a common practice in the whole area. Personal observations at fishing harbours enabled us to estimate that, on average, each fisher takes home between 1–3 kg of fish per day. We estimated total unreported catch due to take-home subsistence fishing could be between 3000 and 8000 t<sup>-1</sup> year<sup>-1</sup>. This represents 2–6% of total estimated catches. When accounting for the non-reporting

in total landings (Fig. 5b), trends in total catches showed the highest value in 1958 with a catch of approximately 400,000 t year<sup>-1</sup>, and a declining trend since the 1960s.

**3.1.2.2. Unreported artisanal and recreational fishing.** Data from fishers interviews was also used to estimate the total amount of artisanal catches (i.e., small-scale commercial) that was unreported



**Fig. 5.** Comparison of different components of total removals (t): (a) official landings, (b) official and non-reporting, and (c) official, non-reporting, recreational, and illegal catch, plus discards (sources: Table S1, 2 and 3 supplementary material).

(Fig. 7a). In principle, artisanal fisheries should be registered in official statistics as other fisheries, but this is not always the case. Of all fishers interviewed, 44% identified artisanal fisheries as important in terms of unreported catches.

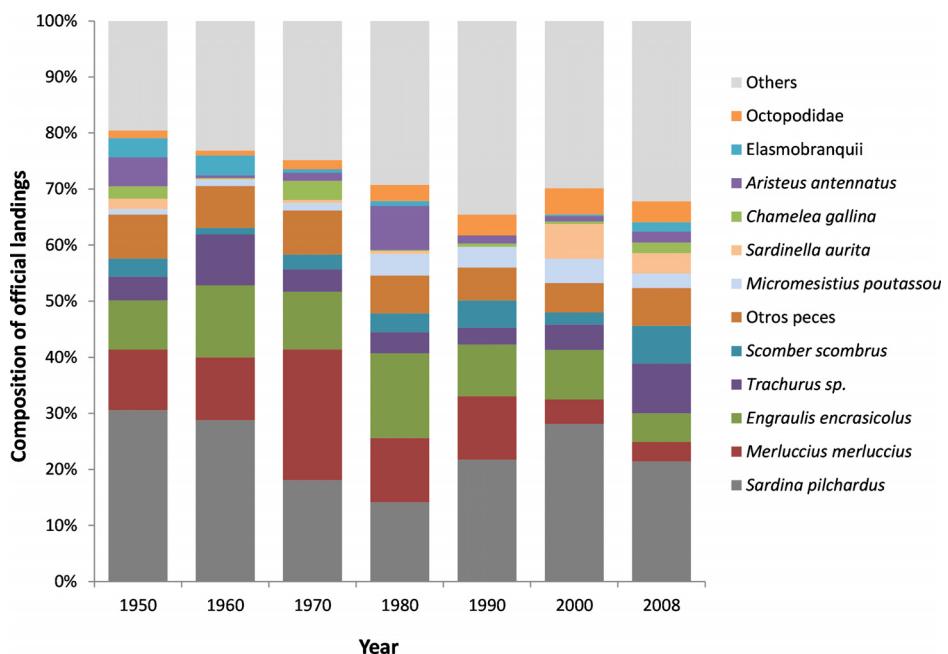
Another important source of unreported catches was the catch from recreational fishing. Recreational fisheries represent a highly diversified activity (Franquesa et al., 2004; Gaudin and de Young 2007; SFITUM, 2006), comprising both shore-based fishing (e.g., pole and line, or diving) and boat-based fishing (including diving).

Despite the importance of this activity, little information on total removals from these activities exists at present (Franquesa et al., 2004) (Table S2, supplementary material). Preliminary studies from the mid-2000s for our study area estimated a total annual fish harvest of 19,740 t (Franquesa 2006; Gaudin and de Young 2007; SFITUM, 2006). By region, Andalusia and Catalonia are the regions with largest absolute values of recreational removals, followed by the Balearic Islands, Valencia and Murcia (Fig. 8a). If recreational removals are compared to commercial catches, the Balearic Islands are the region with the largest recreational catches relative to commercial fisheries, followed by Catalonia and Murcia (Fig. 8b). Overall, recreational catch represented 13.2% of that from commercial fisheries in the mid-2000s. Since historical data on the importance of recreational fisheries were not available, we assumed that its importance was similar back to the 1980s, but was lower from the 1950s to the 1970s (accounting for half of the amount in terms of landings). When we included recreational catches in total catches of the region, the overall trends of total catches peaked in 1958 at approximately 413,000 t year<sup>-1</sup>, then fluctuated to 1982 and declined to a minimum value of 180,000 t year<sup>-1</sup> in the late 2000s (Fig. 5c).

**3.1.2.3. Illegal catches and non-reported catches of vulnerable species.** Unreported catches were also due to (i) illegal catch of commercial species (undersized or species that have quotas such as bluefin tuna), (ii) illegal fishing techniques (such as the Spanish driftnet fishery after the 1992 ban), and (iii) portions of misreported catch of protected species or species at risk (such as pelagic sharks). Illegal catch in the study area was mainly identified to be toward juvenile commercial species (such as juveniles of demersal species as hake or small pelagic fish like sardines or anchovies; see Fig. 7).

However, there is an important component of illegal catch which is directed at commercial large pelagic species, mainly bluefin tuna (ATRT, 2006; Raymakers and Lynham, 1999), and pelagic by-catch species which are frequently vulnerable and data deficient. Studies that analysed the international trade in bluefin tuna from 1998 to 2010 found significant gaps between the catch limits set by ICCAT and the reported amount of bluefin tuna traded on global markets each year (ATRT, 2006; ATRT, 2010; Mielgo Bregazzi, 2011) (Table 3). The percentage of over-quota for bluefin tuna ranged from 5–10% in 1999–2004 to a maximum of 140% in 2010. Using these data, we calculated the percentage of over-quota from 1998 to 2010 and applied it to available bluefin tuna data from ICCAT for our study area (Fig. 4c).

Illegal fishing techniques were also used in the study area. The most problematic was the Spanish driftnet fishery (Silvani et al., 1999; Tudela et al., 2005) (Table 3). Resolutions adopted in 1989 and 1991 by the General Assembly of the United Nations recommended a moratorium on all large-scale pelagic driftnet fishing by 1992. In 1992 the European Community and Spain prohibited drift-net fishing in the Mediterranean with nets more than 2.5 km in length, as did the GFCM in 1997 under a binding Resolution. A total ban on driftnet fishing on large pelagic species by the EU fleet in the Mediterranean entered into force from 2002 (EC, 1998; GFCM, 1997b). Despite these prohibitions, several claims of fraud have been reported after the ban and the activity continues in Mediterranean European and non-European waters (OCEANA, 2005, 2006b, 2007a; Tudela et al., 2005). In the Southern Spanish Mediterranean area, important amounts of by-catch of mainly sunfish (*Mola mola*) and elasmobranches were documented by Silvani et al. (1999) during 1992–1994 while driftnets were targeting swordfish (Silvani et al., 1999). Of total catch investigated, sunfish represented 71% of the catch in 1992, 93% in 1993 and 90% in 1994. To take into account these illegal and non-reported catches until 1994, we quantified the amount of driftnet by-catch of sunfish and other species in the area, and converted total number of individuals by species to

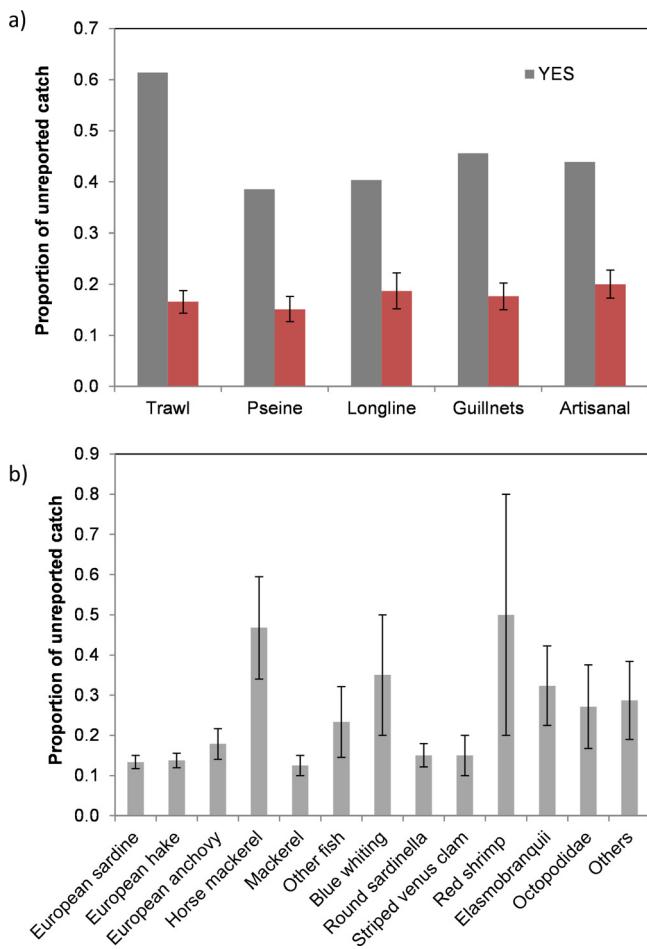


**Fig. 6.** Composition of official landings by main caught species in various years (source: Spanish National Statistics and Autonomous governments, Table S1, supplementary material).

weight (using FishBase, Froese and Pauly, 2013) and scaling total catches to 100% of operations in the area (percentage of followed operations were 1.4%, 3% and 10.2% annually during three years in Silvani et al., 1999). Since the use of driftnets in the Alboran Sea started in the 1980s and lasted until 1994 (Silvani et al., 1999; Tudela et al., 2005), we assumed that historical by-catch had existed since 1975 until the activity of this fleet stopped in 1994 (Fig. 4c). Portions of misreported catch of protected species or species at risk also occur, both for demersal and pelagic species in other fisheries. For demersal species (such as small and medium-size sharks and rays), we tried to capture this catch while quantifying non-reporting going to the black market (see section on black market sales), and this was also included in the estimation of discards, as it seems that most of Mediterranean demersal sharks and rays caught are either discarded or landed as whole carcasses (Hareide et al., 2007). Artisanal fisheries also capture some small sharks and rays, although not in large volumes (Hareide et al., 2007). The main species are small-spotted cat-shark (*Scyliorhinus canicula*) and skates (*Raja* spp.). They may be landed or discarded, depending on the size and price. In case of large pelagic sharks, official data from ICCAT is very poor (Fig. 4b), and most likely substantial underestimates. Spain is the second largest exporter of shark fins to the Hong Kong market after China (Hareide et al., 2007; Lack and Sant, 2011; OCEANA, 2008) and fin sale is a profitable activity for Spanish fisheries (OCEANA, 2007b, 2008). Unfortunately, it is unclear what proportion of Spanish pelagic shark catches come from the Mediterranean Sea (Hareide et al., 2007; OCEANA, 2008). There are no specific Mediterranean pelagic fisheries targeting migratory oceanic sharks, but these species constitute a large component of by-catch in tuna and swordfish fisheries operating in coastal and offshore waters using long lines, driftnets, purse seines and Almadrabas (or fixed tuna traps) (Hareide et al., 2007; Macías et al., 2004; Megalofonou et al., 2005; Silvani et al., 1999). Some shark data from illegal driftnets in Spanish waters were already available from Silvani et al. (1999) to complement ICCAT official data from the 1980s to 1994 as explained above. Data from ICCAT (<http://www.iccat.int>, Task I) came mainly from surface long-line that target tuna and swordfish in the Spanish Mediterranean Sea.

Long-lining emerged at the beginning of the 20th century in this area, with a clear expansion in the 1960s to 1980s (Macías et al., 2004; Rey et al., 1988). Although data are not abundant about this fishery, a study in 2001–2002 in the Western Mediterranean documented important amounts of elasmobranchs and other non-commercial species in the catch (Macías et al., 2004). The study described that in 2001 and 2002, elasmobranchs were 0.5–1% of swordfish catches (mainly thresher sharks *Alopias* spp. blue shark and shortfin mako *Isurus oxyrinchus*) and other species represented 2–4% of swordfish catches (including sunfish, sting rays *Dasyatis* spp., and other non-commercial fish) (Macías et al., 2004; OCEANA, 2006a). Another study carried out by observers at landing sites and on-board fishing vessels was used to complement the information about total catch of sharks (Megalofonou et al., 2005). The authors documented incidental catches and discards of sharks from long-lines and driftnets and provided information on species composition, distribution, and abundance.

Comparing the above information about by-catch of large pelagic sharks and official data from ICCAT, it was clear that the latter seemed to be incomplete (Fig. 4b). Therefore, we complemented the official dataset using the official swordfish catch to calculate by-catch of sharks and other non-commercial species (assuming 10% for sharks and 3% of other species) (Fig. 4c). Additionally, in fixed tuna traps, the main species of elasmobranchs traditionally caught as by-catch were large individuals of common thresher, basking shark (*Cetorhinus maximus*), blue shark (*Prionace glauca*), devil ray (*Mobula mobular*) and sometimes great white shark (*Carcharodon carcharias*), but only data from Italy exists (Hareide et al., 2007). Therefore, we assumed a 5% by-catch of large pelagic sharks in Spanish Almadrabas from 1950 to 2000 (Fig. 4c). After accounting for different sources of illegal catch or by-catch of pelagic species, catches were higher for driftnets, followed by the over-quota of bluefin tuna (Fig. 4c). However, when accounting for these illegal catches in total catches from the study area (Fig. 5c), illegal catches made a low contribution to total removals: the highest value was still observed in 1958 with approximately 414,000 t year<sup>-1</sup>, fluctuated to 1982 and declined to a minimum of 182,000 t year<sup>-1</sup> in 2008–2010.

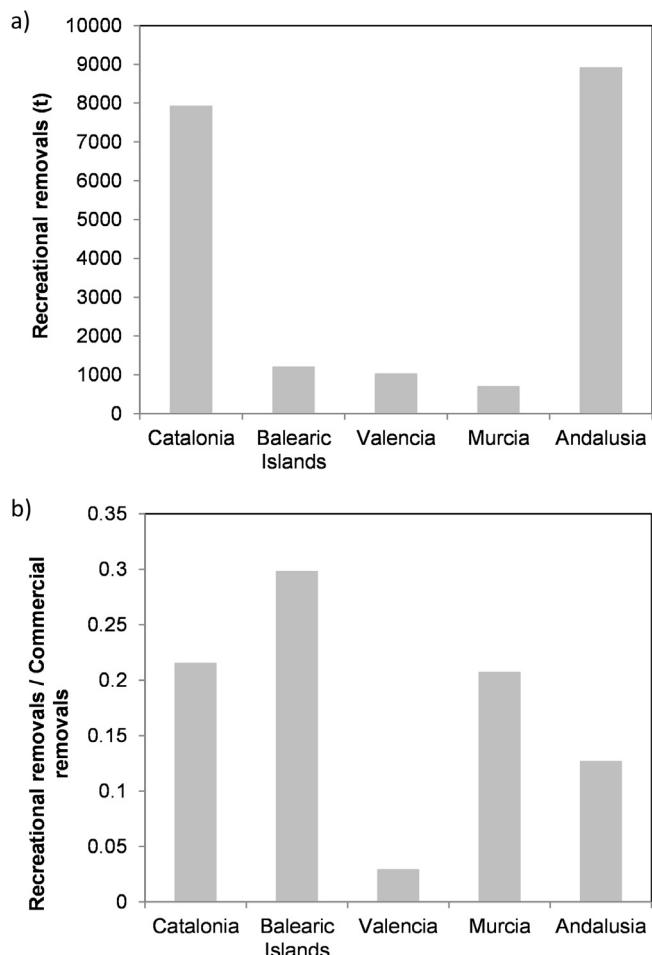


**Fig. 7.** Proportion of unreported catches (a) by fleet and percentage of fishers affirming that non-reporting exists by fleet and (b) by main caught species.

### 3.1.3. Discards

Discarding by bottom trawls ranged from 14 to 57% of official landings, depending on regions and time period (Fig. 9a). In 2009–2011, we could retrieve information by region and fishing fleet (Fig. 10b). Discards from trawling, purse seine and gillnets were overall high in Catalonia, Valencia and Southern Mediterranean area (Fig. 9b). These results are presented as the percentage of discards with respect to total landings. In the case of percentage of discards by fleet (Fig. 9b), gillnets and artisanal gears show important percentages of discards in the Balearic Islands and Andalusia, but since they are expressed as a fraction of official landings by fleet, the absolute amount of discards by these fleets is lower than the ones generated by trawling.

Historical data available from other fleets showed that in Catalonia, discards from purse seine may have slightly increased from the 1990s to 2010, while long-line discards could have slightly decreased (Fig. 9c). Discards from the artisanal fishery in the Gulf of Cadiz may have experienced an increase from the 1990s to 2010 (Fig. 9c). Data on discards by main species in the catch illustrated that several species, including commercial species, are subjected to discarding (Fig. 9d). Although available data from trawling showed an increase of discards from the 1990s to 2010 (Fig. 9a), most interviewed fishers stated that, overall, non-targeted catch had declined with time (47%), with a mean decline of –7%. On the other hand, some fishers suggested that it had increased over time (17%), and a quarter considered that discarding remained unchanged (26%). The rest stated they did not know or did not answer.



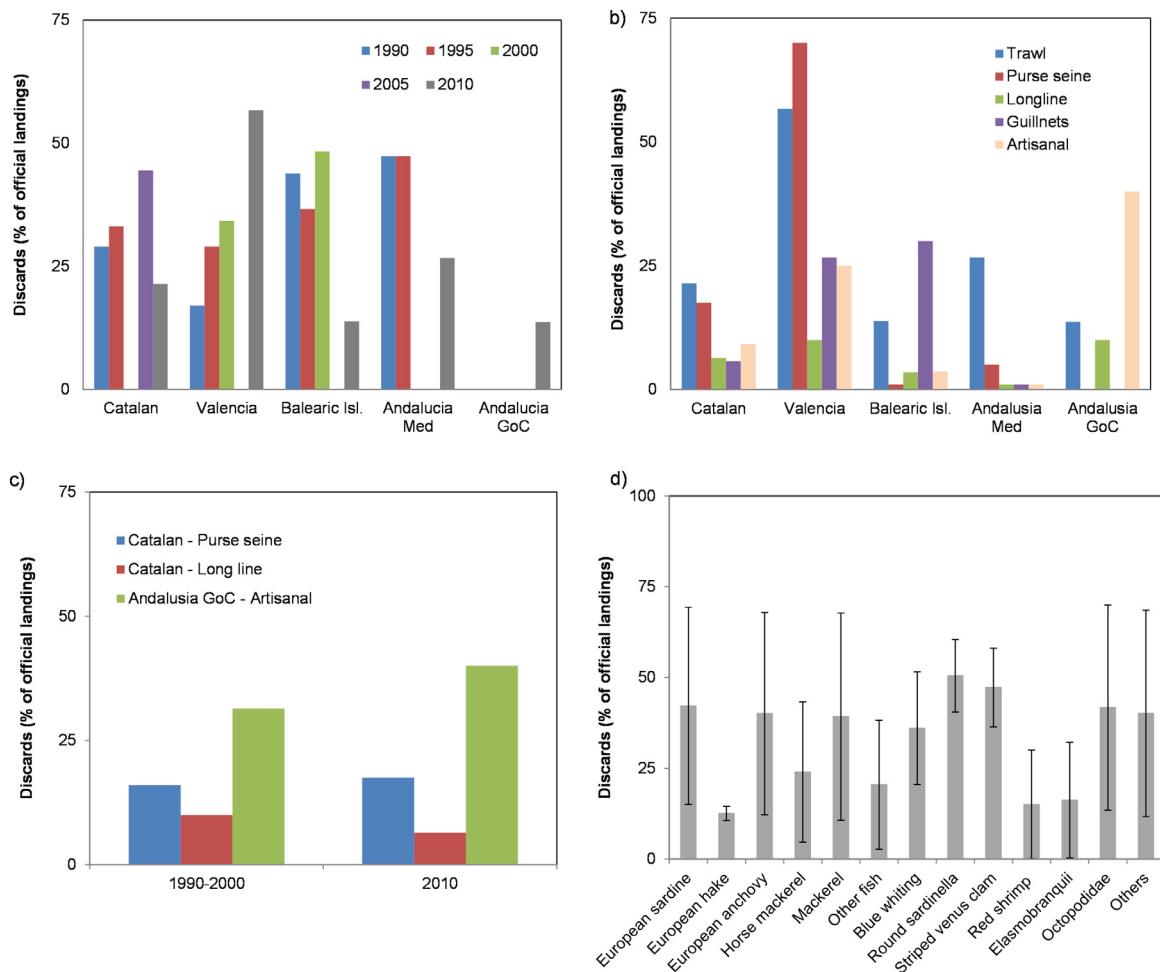
**Fig. 8.** Recreational removals (t) by (a) region and (b) in comparison with commercial official landings (sources: [Franquesa, 2006](#); [Gaudin and de Young, 2007](#); [SFITUM, 2006](#)).

Using the data available from boat-based discards in the study area (Fig. 9), we estimated total boat-based discards. Since it was not obvious that discarding changed with time, we used data from the 1990s to 2010 as representative of the entire time period from 1950 to 2010. This decision may be underestimating discards in the past if discarding has truly decreased with time as several fishers stated. Additionally, taking into account that estimated ghost catches in European waters are generally believed to be approximately 1% of official catch ([Brown et al., 2005b](#)), we added an additional 1% of coastal demersal fish and invertebrates that were killed/discharged due to ghost fishing.

When accounting for these boat-based discards and ghost catches in the total catch estimates (Fig. 5c), discards made an important contribution to total catches: the highest value was observed in 1958 with approximately 515,000 t year<sup>-1</sup>, fluctuated to 1982 and declined to a minimum of 229,000 t year<sup>-1</sup> in 2008–2010.

### 3.2. Total fisheries catches compared to official landings

Total fisheries removals were estimated by summing all catch components investigated here: official reported landings, discards and unreported catches. The three components represented important portions of total removals (Fig. 10a): In late 2000, official landings represented 56% of total catch, followed by discards (with a mean contribution of 21%) and unreported landings with 20%. The rest of the catch is due to recreational fisheries and catch of



**Fig. 9.** Total discards as % of official landings: (a) from trawling in different time periods, (b) by region and fleet in late 2000s, (c) from purse seine, long line and artisanal in different time periods, and (d) by main caught species (sources: Table S2, supplementary material, and fishers' interviews in 2009–2011).

large pelagic fish (ICCAT mainly). Unreported catch was 43% of total removals in the area.

Unreported landings were investigated in terms of black market and subsistence fishing, artisanal fishing and recreational fishing. They also included a small portion of illegal catch. Of these elements of unreported catch, in 2010 recreational fisheries was the most important (~36%), followed by black market (~32%), subsistence fishing (~17%), artisanal (~12%) and illegal catch (~2%) (Fig. 10a). Total removals were mainly assigned to the industrial sector (Fig. 10b), while discards followed in terms of total removals. Artisanal, recreational and subsistence fishing removed smaller amounts of catch from the ecosystems (Fig. 10b).

When accounting for all fisheries removals (Fig. 10a), we observed a maximum catch of 516,054 t year<sup>-1</sup> in 1958, thereafter total catches gradually declined with substantial fluctuations until 1982, after which catches declined to a minimum value of 227,333 t year<sup>-1</sup> in 2008. When compared to official estimates of landings from FAO (Fig. 10) a different trend emerged: while official landings showed an increase of landings from 1950 to the mid-1960s and a clear decline from early 1980s to date, reconstructed total catches showed an earlier peak of total removals in the late 1950s, and a decline from the mid-1970s to the present.

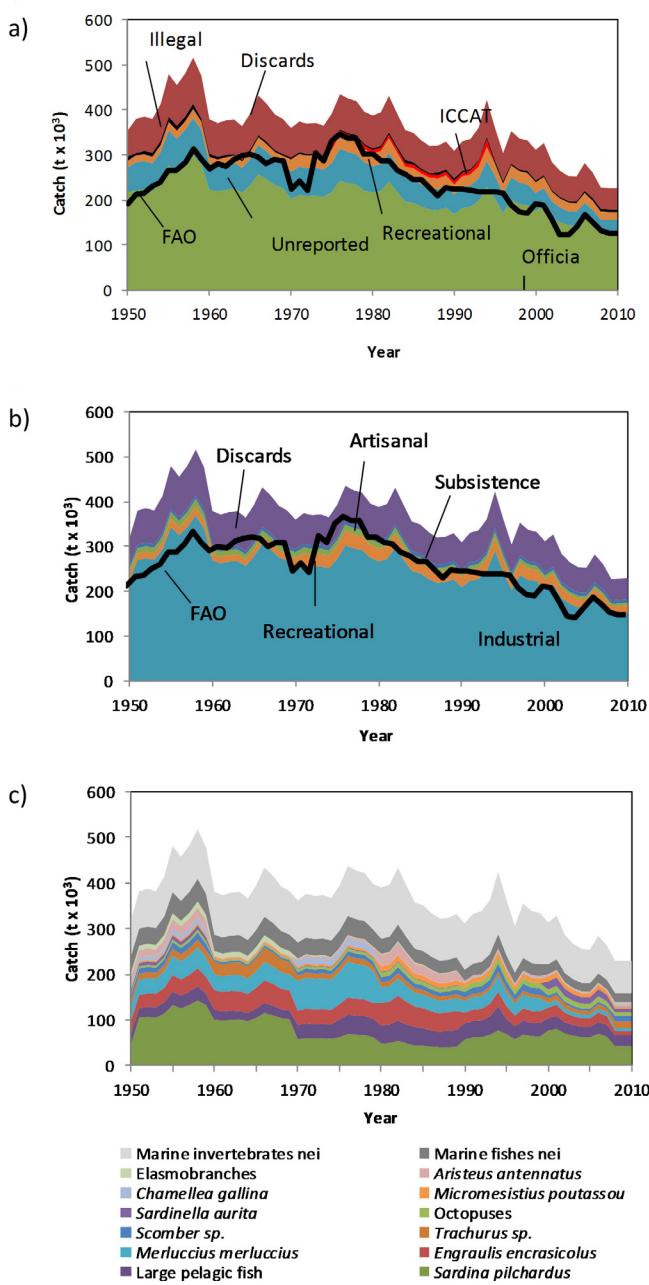
By species, sardine, hake and anchovy contributed the bulk of removals, although the catches are very diverse in terms of taxa (Fig. 10c). Clear declines with time were observed for important commercial species such as hake, anchovy, and sardine, while other species increased in the catch in recent years, such as round

sardinella, other pelagic fish such as mackerel and blue whiting, and octopuses and other invertebrates.

#### 4. Discussion

This study provides a first estimate of total fisheries removals from the Spanish Mediterranean Sea and Gulf of Cadiz regions (1950–2010), and it is the first of its kind in the area. Despite several limitations highlighted below, this study shows that IUU catches may be large in Southern European and Mediterranean regions, making up an average of more than 40% of total fisheries removals, including discards. This percentage of IUU catches increased with time from 1950 to 2010 and was always more than 38% of the total catch in our study area.

These overall IUU estimates are in line with the estimates of the European Court of Auditors (Court of Auditors, 2007), where it was noted that Spain may be non-reporting 40% of total catches. On average, our estimate is higher than the preliminary global average of 18% calculated for 2000–2003 (Agnew et al., 2009). Other estimates of IUU in Mediterranean ecosystems highlighted high IUU proportions of the catch, e.g., in Corsica (with 5 times more catch than officially reported, Le Manach et al., 2011), in the Balearic Islands with 2.3 times more catch (Carreras et al., 2013), the 35% IUU in Greek waters (Tsikliras et al., 2007) or the 63% in Turkey (Ulman et al., 2013). Our estimates are similar than that for Greek waters, but smaller than the ones from Mediterranean Islands and Turkish waters. This is logical since the two Mediterranean Islands studied



**Fig. 10.** Total fisheries removals (t) in the Spanish Mediterranean Sea and Gulf of Cadiz regions (1950–2010) by main sources of removals: (a) official catch, discards and unreported catches (artisanal, subsistence and black market), recreational, ICCAT and illegal catches, (b) by industrial, artisanal, subsistence, recreational and discards, and (c) by main species. FAO official data is indicated (black line).

are highly dependent on tourism, and infrastructure to record and monitor catches is lacking, while the difference with Turkey may be related with different mechanisms to report catches between European and non-European countries.

Unreported catches, including discards, represent a significant handicap to the work of regional and international organizations, and assessments by fisheries scientists. They bias data availability and therefore our ability to understand how fishing activities impacts species, marine communities and ecosystems (Malfada et al., 2013; Zeller and Pauly, 2007). When fishing data are underestimated, the impact of fishing is also underestimated, which may threaten not only exploited resources but also the future economic viability of the fishing industry. Therefore, the estimates of total

fisheries removals we present in this study represent an improvement over official data, and should be taken into account when progressing towards ecosystem-based fisheries management, since fishing mortality for many species may be higher than previously estimated. This study shows that relying solely on officially reported data may imply the underestimation of fishing mortality. Our results are especially important in the context of the European Data Collection Framework and the MSFD since data of good quality is currently needed to inform management within the European Union.

It has to be noted, however, that these first estimates of IUU catches by Spanish fisheries could still be underestimated because important information gaps still exist, especially in historical time series. For example, this study did not include IUU practices related with aquaculture activities, and the by-catch of vertebrate species such as marine mammals, seabirds, and marine turtles (Biton Porsmoguer, 2009; Camiñas, 2004; Camiñas and De la Serna, 1995; Silvani et al., 1999; Tudela, 2004), the collection of algae, and the exploitation of highly valuable corals such as the red coral *Corallium rubrum* (Tsounis et al., 2007).

Moreover, data reconstructed for commercial fish and invertebrates is approximate due to uncertainties associated with the estimates (Table 3) and misidentification of landed species (e.g., Oltra et al., 2008). Future efforts to improved data on species identification are fundamental.

The fishers interviewed for this study confirmed the existence of a black market. Although the true amount of catches that go into the black market is very difficult to estimate, fishers provided a first estimate of the magnitude of this black market. Furthermore, in 2007, the EU Court of Auditors stated that in Spain the sale notes for frozen produce were not recorded, even though the quantities they represented were very substantial (Court of Auditors, 2007).

Some species may be more vulnerable to being unreported or under-reported. For example, it is clear that catches of juvenile hake are substantially unreported, as they represent a substantial part of illegal catch. Trawling for hake, which has been the most important demersal target species in the Mediterranean in the past, has resulted in catches that consist almost entirely of immature fish (Oliver, 2001). Other examples are sardine and anchovy, as they are subjected to substantial market price fluctuations and have been heavily discarded through all the time period analysed (Table 3). Total removals of these species have declined over time in our study, likely suggesting overfishing in line with existing assessments (Abdul Malak et al., 2011; Palomera et al., 2007). Additionally, the growing demand of feed for cage-tuna may pose some pressure on unreported catch of small pelagic fish (I. Palomera, Institute of Marine Science of Barcelona, pers. comm.). Therefore, specific studies about unreported and discarded events of these highly caught species could improve our estimate of total catch removal of fisheries from the Spanish Mediterranean Sea and Gulf of Cadiz regions.

Recreational fisheries also produce discards, which we did not take into account (Franquesa et al., 2004; SFITUM, 2006). Catches by recreational fisheries are an important part of total fisheries removals and its importance has grown over time, since game fishing is a growing leisure activity in many Mediterranean areas (Franquesa et al., 2004; SFITUM, 2006). However, large unknowns still exist in terms of total catch and discards. In addition, the use of aquatic resources as bait in recreational fisheries is an issue to be investigated.

In this study, we assessed the contribution of illegal catch to total removals, especially of illegal catches from driftnets during the 1980s and 1990s. However, other sources of illegal catch also exist. For example, fishing likely occurs in protected or restricted areas (Lloret et al., 2008a,b), or with other illegal gear with small mesh size. Information regarding these activities is not available,

and would require an in-depth investigation of fishing activities. Additionally, a variety of medium-scale and industrial pelagic long-line fleets targeting large pelagic fish operate in Mediterranean waters, ranging from local coastal state fleets to large industrial foreign fleets, including Japanese, Flag of Convenience (FoC), and even non-flagged “pirate” fleets. The present reconstruction included only data from the Spanish domestic fleet reported to ICCAT. We also included unreported unofficial data from independent assessments. However, FoC and pirate fleets are estimated at about 100 vessels (GFCM, 1997a), and there is no data on catches (Tudela, 2004). Moreover, although there is little data on by-catch from purse seiners in the Mediterranean Sea, accidental catch of large organisms occurs (Fromentin and Farrugio, 2005). Occasionally some basking sharks or devil rays are also captured by artisanal fisheries, but quantitative data are not available (Bartolí, 2009).

Our study highlights the importance of artisanal fisheries in the area. The diversity and economic importance of artisanal gears in small-scale fisheries are essential features of Mediterranean fishing (Tudela, 2004). Data available suggests that the artisanal sector is also involved in producing substantial amounts of discards and unreported catches (Tudela, 2004). In the Gulf of Cadiz, recent investigations have concluded that catches of the striped venus clam since the 1990s have largely increased but have been mainly unreported (Silva and Juarez, 2009). This data were not included in our study due to the coastal nature of the fishery (between 5 and 15 meters of depth). Artisanal fisheries are also responsible for high rates of abandoned gear that can be potentially important for ghost fishing. The massive use of fixed nets (and other artisanal gears such as traps) in many small-scale Mediterranean fisheries, makes ghost fishing by abandoned or discarded gears a problem in Mediterranean waters but has attracted scant attention (Tudela, 2004).

Our study also illustrated that discards are another important source of unreported catches. Our findings highlight that the general estimate of discards for the Mediterranean and Black Sea of 4.9% from Kelleher (2005) was unrealistically low for this region. Discards are produced due to several reasons in the area, for example, due to (i) discards of caught juveniles smaller than the legal landings size, (ii) discards of species of legal size, but with low or no market value, (iii) discards due to willing to better use the capacity of the boat to keep other species with higher commercial value (the so called ‘upgrading’), and (iv) discard of illegal species. In our study, we were only able to take part of all discards into account and thus our results are likely underestimates. Scattered quantitative data existed about boat-based discards of bottom trawling activities in the study region, which is mainly linked to demersal species but can also discard small and medium-sized pelagic fish, but data regarding discards from other fishing techniques is less abundant.

Our approach required occasional inferences and interpolations that are also documented. We justify them, despite data uncertainties, given the less acceptable alternative outcome which is the interpretation of non-reported or missing data as zero catches (Zeller and Pauly, 2007). We were motivated by the fact that estimates of total fishery removals are the most fundamental data to understand and assess the role of fishing on exploited ecosystems. When fishing data are underestimated, the impact of fishing is also underestimated, which may threaten not only exploited resources but also the future economic viability of the fishing industry.

Therefore, and despite above limitations, our study presents an example from Southern European and Mediterranean fisheries on how to proceed to estimate total fisheries removals. Our estimates enabled us to observe that catch from the area had overall declined since mid-1960s, although overall fishing effort and fishing capacity had increased substantially from 1960s to date (Table 3, Coll et al., 2014). In fact, significant technological changes have occurred over

the last 60 years and incentives for fishing development and fishing laws have changed and evolved over time (Bas, 2009; Bas et al., 1985, 2003; Coll et al., 2014). Our results thus suggest a general declining catch per unit of effort, a clear indicator of overfishing, and highlights that depletion of marine resources in the region started earlier than we previously thought analysing the official data. The region was already being depleted in the 1950s and 1960s, in line with the general perception of its long history of exploitation (Coll et al., 2010; Fortibuoni et al., 2010; Lotze et al., 2011; Sobrino et al., 1994).

Additionally, species that were less important in the catch had been increasing their importance with time, resulting in a diversification of species that are now for sale in fish markets. This is a sign of expansion of fishing to species that were less appreciated in the past. These species may also indicate ecosystem changes with time in line with results from historical information (Coll et al., 2014).

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.fishres.2014.01.013>.

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