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Contribution to the Themed Section: '*Marine recreational fisheries – current state and future opportunities*'

Original Article

Recreational and small-scale fisheries may pose a threat to vulnerable species in coastal and offshore waters of the western Mediterranean

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This study evaluates the fishing pressure exerted by the most common recreational and professional, small-scale fishing practices on vulnerable target and bycatch species in coastal and offshore waters of the western Mediterranean. By combining multiple data sources, we assembled a unique dataset on catches at multiple sites in these areas by recreational (RF) and small-scale fisheries (SSF), covering the period from 1997 to 2015. Furthermore, a framework with which to identify the vulnerable species among all the species caught is provided; it is based on the IUCN Red List, international conventions for the protection of flora and fauna, the Habitats Directive and the intrinsic vulnerability index of marine fish. Overall, about a quarter of exploited species targeted by SSF and RF in coastal waters were vulnerable, making up nearly 50% of the total SSF catch and nearly 20% of the total recreational catch. In offshore waters, 100% of the RF and SSF catch was made up of vulnerable species. Among the species caught as bycatch in both areas by SSF and RF, there was a total of 27 vulnerable vertebrate species, which

included birds, cetaceans, elasmobranchs and sea turtles. Our results highlight the need to differentiate between different fishing methods or gears when studying the fishing impacts on vulnerable species. The results also indicate that, although RF and SSF are often considered to have a relatively low ecological impact, a range of different fishing methods are affecting vulnerable species in coastal or offshore waters in the western Mediterranean Sea, be they targeted or taken unintentionally as bycatch.

Keywords: fisheries management, marine protected areas, recreational fisheries (RF), small-scale fisheries (SSF), target and bycatch, threatened species

Introduction

The magnitude of the ongoing extinction crisis has generated a huge effort aimed at evaluating and monitoring the risk of extinction faced by species worldwide. The trade-offs between economic, social, and conservation objectives become severely problematic when the vulnerability of exploited species to fishing is high and the economic value of these species is also high (Norse *et al.*, 2012). Increasing global consumption of marine resources, together with environmental changes, has led to widespread loss and degradation of marine ecosystems, with potentially serious consequences for biodiversity and ecosystem services (Bianchi and Morri, 2000; McCauley *et al.*, 2015; Webb and Mindel, 2015). Throughout the world, many exploited marine species are experiencing declines in population because of overfishing and other stressors, including climate change. Moreover, the systematic differences among different species in their sensitivity to fishing is partly responsible for the increasing dominance of less vulnerable fish species in global catches, as the vulnerable ones become easily overexploited (Cheung *et al.*, 2007). Consequently, global, regional, national, and local lists of threatened species, including those listed in the international conventions for the protection of flora and fauna, have proliferated over the past decades (Burton, 2003) and these lists and conventions have undeniably become valuable tools for conservation (Dulvy *et al.*, 2006; Rodrigues *et al.*, 2006; Miller *et al.*, 2007). Recently, the IUCN Red List has been proposed as a tool to complement or enhance existing indicators for sustainable use of marine resources, as described in the European Commission's Marine Strategy Framework Directive for monitoring, which applies an ecosystem approach to fisheries management (EC, 2014). Furthermore, quantitative indices, such as the intrinsic vulnerability (IV) index of marine fish (Cheung *et al.*, 2007), have been developed to address the specific vulnerability of fish to external pressures.

Recreational and small-scale (professional) fishing are important socioeconomic activities in the Mediterranean, taking place in coastal areas, as well as in offshore waters (reviewed by Lloret *et al.*, 2018). Recreational fishing (RF) in the Mediterranean, according to Font *et al.* (2012), comprises all non-commercial fishing that is carried out for leisure or sport, where the catch—the selling of which is illegal—is for one's own consumption (or for family and friends). It is particularly popular in the European Mediterranean, with the total number of recreational sea fishers estimated to be ∼2.8 million (Hyder *et al.*, 2018), but also in non-European countries such as Tunisia (Ben Lamine *et al.*, 2018) and Turkey (Tunca *et al.*, 2016). The Mediterranean has an extensive coastline, a huge population living in coastal areas (150 million people according to IUCN, 2019) and the importance of fishing as a leisure or tourist activity is increasing (Font *et al.*, 2012). The expenditure by European recreational sea fishers in the Mediterranean has been estimated to be around 920 million € (Hyder *et al.*, 2018). In coastal waters (less than, approximately, 12 miles from the shore), RF methods are highly diverse, including boat fishing, shore fishing, spearfishing and shellfish gathering, sometimes carried out individually and sometimes in groups (e.g. in competitions and on chartered boats) (Font *et al.*, 2012). In offshore waters (more than, approximately, 12 miles from the shore), various gears are used by recreational boat fishers, such as rods with line and reel and trolley rigs, and they mainly target large pelagic predatory fish species, which include sharks, although information is scarce (Fowler *et al.*, 2005; ADAP, 2017).

Professional, small-scale fishing (referred to as SSF throughout this article) is defined, according to the European Parliament (2014), as "fishing carried out by fishing vessels of an overall length of <12 m and not using towed fishing gear." SSF involves boats with smaller crews (one to three fishers per vessel) and uses a wide variety of fishing gears, including trammel nets, gillnets, longlines, and pound nets, which are mostly passive gears targeting a wide array of seasonally changing benthic and pelagic coastal species (Lloret *et al.*, 2018). Offshore SSF mostly targets large pelagic predatory fish using, in most cases, pelagic longlines (Biton-Porsmoguer and Lloret, 2018). Although there are also other offshore fishing vessels using bottom longlines and gillnets to target benthic demersal fish, such as European hake (*Merluccius merluccius*) and blackspot seabream (*Pagellus bogaraveo*), these vessels are often >12-m long (STECF, 2004) and therefore cannot be considered as SSF. SSF is of great importance in terms of job opportunities and their contribution to the economy of coastal communities in Europe: they have been estimated to generate about half of all direct employment within the EU fishing sector, representing ∼83% of the fishing vessels and a quarter of the catch value (Guyader *et al.*, 2013; FAO, 2018). According to recent estimations (Hyder *et al.*, 2018), in a number of northern European countries, removals by marine recreational fisheries account for a significant proportion (up to >50%) of the total removals (both recreational *and* commercial) of species such as western Baltic cod (*Gadus morhua*) and European sea bass (*Dicentrarchus labrax*).

RF and SSF in European waters, and particularly in the Mediterranean, involve smaller catches, lower impact on habitats, lower annual fuel oil consumption, less bycatch and discards, and less of the catch is reduced to fishmeal and oil than is the case with large-scale fisheries such as trawling and purse seining (Kelleher, 2005; Tsagarakis *et al.*, 2014; Lloret *et al.*, 2018). Consequently, they are often considered to have a smaller ecological impact. However, from a biological standpoint, there are several features of these fisheries that may threaten the conservation status of certain species (Lloret *et al.*, 2018). Such species include benthic and pelagic long-lived and slow-growing species with low reproductive potential and a narrow geographic range (e.g. Luna-Pérez, 2010; Lloret and Font, 2013; Lloret *et al.*, 2012; Biton-Porsmoguer and Lloret, 2018). Furthermore, there is a widespread international agreement that bycatch in many fisheries raises ecological concerns that require the urgent attention by

fisheries management (Zeller *et al.*, 2018). Although some studies have looked into the impact of specific small-scale and RF gears on particular vulnerable species in the Mediterranean (e.g. Morales-Nin *et al.*, 2010; Font and Lloret, 2014; Biton-Porsmoguer and Lloret, 2018), none of these studies have assessed the overall impact of small-scale and recreational fisheries on vulnerable species in an integrated way, taking into account both coastal and offshore waters, as well as target species and bycatch species, and the different fishing gears employed.

The goal of this study is to evaluate and compare the fishing pressure exerted by SSF and RF operating in coastal and offshore waters of the western Mediterranean Sea on the vulnerable species exploited in these waters (target species and bycatch), taking into account, when possible, the differentiated effect of each small-scale and RF method or gear. To our knowledge, this is the first holistic study of its kind because, until now, only limited results have been published focusing on particular fishing sites, specific areas, fishing gears, or species. The study also proposes a number of management recommendations for a more effective protection of vulnerable exploited species in coastal zones and offshore, particularly in marine protected areas (MPAs) and the "Special areas of conservation" (SACs) in the Mediterranean Sea. SACs are those areas which have been given greater protection under the European Commission's Habitats Directive. It must be considered that most of the species targeted by SSF and RF are not regularly assessed on a broader scale, and very few and coherent management actions (e.g. quotas, minimum landing sizes, etc) have been implemented so far in the Mediterranean. Only a small number of species, such as bluefin tuna (*Thunnus thynnus*), swordfish (*Xiphias gladius*), and European hake (*M. merluccius*), are currently assessed and managed. In this sense, this study proposes a framework to identify which of the exploited species can be described as vulnerable to fishing pressure from SSF and RF, and for which, consequently, priority management measures should be undertaken in order to attain the favourable conservation status (FCS) (defined in the Habitats Directive) for these species and the habitats they inhabit.

Methods

Catch of target species

By combining multiple data sources, including reports, scientific literature, and catch data provided by fisheries and MPA managers, we assembled a dataset on SSF and recreational catches at multiple sites, covering both coastal and off-shore areas, in the Mediterranean Sea.

Information on RF was gathered in 20 coastal areas (14 of which are MPAs and 13 are SACs; Figure 1) from three EU Member States (Spain, France, and Italy), within the framework of the EU SAFENET project (Sustainable Fisheries in EU Mediterranean waters through a network of MPAs). These areas include the north-eastern part of the Catalan Sea, the Gulf of Lion, the Ligurian and the northern Tyrrhenian Seas, and the islands of Corsica and Sardinia.

Information was collected from a total of 40 studies comprising scientific articles (8) as well as grey literature (32) including unpublished reports and documents provided by researchers and managers of MPAs, where most of the research regarding RF in the Mediterranean has been carried out. These studies were carried out in a variety of ways encompassing a diverse range of sampling periods, duration and different RF methods (Supplementary Table SB1). For the purpose of this study, fishing methods are defined as: boat fishing (BF), shore fishing (SF), and spearfishing (SP). Although some of these studies did not always classify the data according to fishing methods, and for certain areas there is a lack of information regarding particular fishing methods, those we have reviewed represent the best source of available information so far. It must be pointed out, nevertheless, that there is very little information on RF outside spring and summer, during which the vast majority of samplings (90%, all areas combined) were carried out (Supplementary Table SB1). Therefore, our analysis is representative of the warmer season only, which is nevertheless the high season for RF in most of the areas (Font and Lloret, 2013, 2014). In addition to the revision of literature, the managers of each MPA and seven local scientists who specialize in coastal fisheries were contacted by email to obtain information on the catch of vulnerable species by recreational fishers through standardized questionnaires designed specifically to gather the same information from each area (i.e. the presence of vulnerable species in the catch of recreational fishers). Around 65% of the managers and scientists contacted provided the information required for further analysis. The rest were unable to provide information because their MPAs had only recently been created, which meant sufficient data on RF activity had not yet been collected.

The available information from SSF was provided by monitoring in three MPAs where information was available: Cap de Creus (Spain), Côte Bleue (France), and Cerbère-Banyuls (France). Studies in Cap de Creus MPA were conducted in 2008, 2009, 2010, 2011, 2013, and 2015 via 572 onboard samplings, mostly carried out in spring and summer. The sampling scheme had two components. The first involved interviewing small-scale fishers and conducting on-board inspections. Fishers were interviewed and a sampling report was completed, which included the fishing gear used, location (fishing site), the date and time that the gear was set or cast and when it was removed, and the quantity of fishing gear (number of hooks, length of nets, etc). The second, employing an increasingly common method for collecting fishery data, consisted of a self-sampling programme by the fishers themselves enabling them to provide information from their own fishery. Overall, different boats from the various ports in the Cap de Creus area where small-scale fishers land their catches were sampled to gather information according to fishing method (trammel net, gillnet, longline, and pound net). Meanwhile, data on species and catches from the Côte Bleue MPA were gathered during 261 small-scale fishing operations—involving trammel net, gillnet, and longline—that were carried out in all seasons from 2012 to 2015. In this MPA, some species (mainly small-sized species such as labrids and serranids with little or no commercial value) were not taken into account because of insufficient data. Finally, the data on species and catches from the Cerbère-Banyuls MPA were gathered during 2015 (spring and summer), but only for trammel net fishing operations. The available information from these three MPAs was then collated with the aim of studying the effect of fishing method. Unfortunately, a wide range of sources were used to gather all the available information, which meant the data were heterogeneous in terms of fishing gears, years and seasons (i.e. the same data on all types of gears or years or seasons were not available for each area). Therefore, we proceeded to pool what data we had from all areas and only considered testing the effect of fishing method. Further details of the sampling methodology employed to monitor SSF in Cap de Creus, Côte Bleu, and

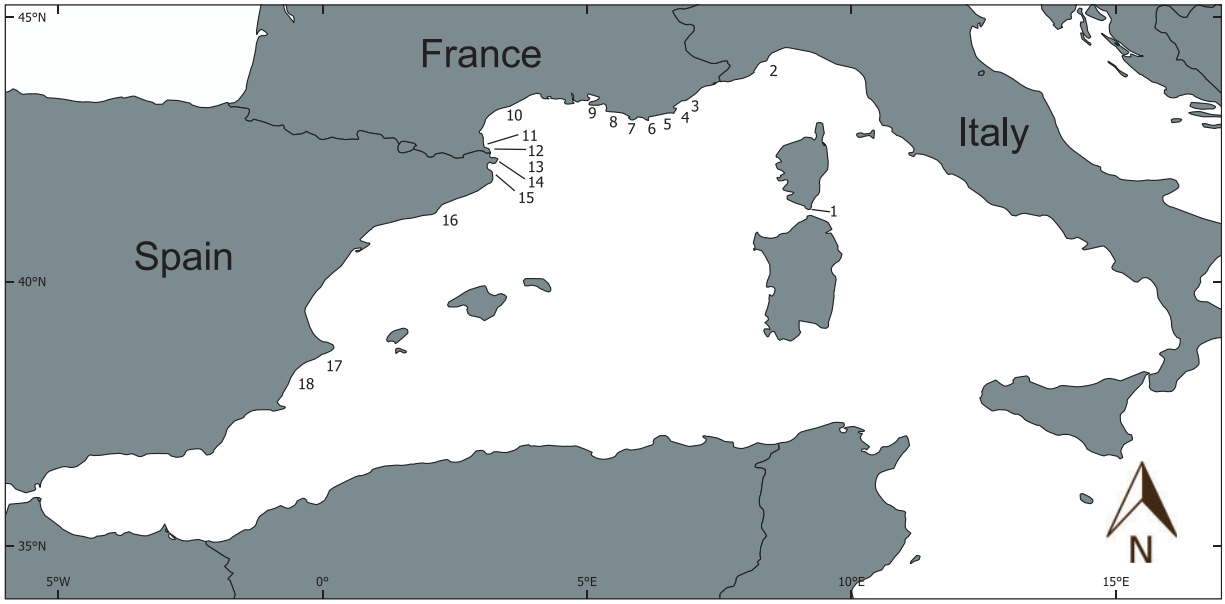

Figure 1. Map of the study area showing the coastal areas and MPAs considered. The code numbers are: 1—Bonifacio*; 2—Bergeggi (adjacent area); 3—Cap Roux (adjacent area); 4—French Riviera*; 5—Port–Cros*; 6—Porquerolles*; 7—Archipel des Embiez—Six Fours*; 8—Archipel de Riou; 9—Côte Bleue*; 10—Cap d'Agde*; 11—Côte sableuse catalane; 12—Posidonies Côte des Albères *; 13—Cerbère–Banyuls*; 14—Cap de Creus*; 15—Medes Islands*; 16—Coast of Catalonia; 17—Serra Gelada*; and 18—Tabarca*. The sites marked with the symbol * are designated (wholly or partially) as Special areas of conservation (SACs).

Cerbère-Banyuls MPAs are given in Charbonnel *et al.* (2013, 2017), Lloret (2015), and Prats (2016), respectively.

Information relating to offshore catches was only available for the Spanish Mediterranean coast. Data on the catch of pelagic species by RF, gathered in 2017, were provided by the Spanish General Secretary of Fisheries. The raw data gives the number of individuals caught; hence, the total weight of the catch by species was estimated by multiplying the number of individuals caught by the estimated weight of the individuals. We estimated an average weight of 15 kg for each specimen of swordfish, given that the Spanish authorities stated that individuals weighed <20 kg and the minimum legal weight is 10 kg. For tuna species, we also estimated an average weight of 15 kg for each specimen, using information provided by the fishers. Additionally, in the catch there were some specimens of European hake; in this case we assumed an estimated average weight of 0.6 kg for each specimen, again using information provided by the fishers. With regard to the SSF catch of pelagic species, data were obtained for 2017 from the landing statistics recorded by the Autonomous governments of Andalucía, Murcia, Valencia, Catalonia, and the Balearic Islands.

Vulnerability of target species

From the catch made by SSF and RF in coastal waters and offshore, we first identified those exploited species that can be considered as "vulnerable to fishing" (Supplementary Table SB2). To do so, we first selected all the species in the catch that are included in the IUCN Red List - Mediterranean regional assessment (www.iucnredlist.org) as *Threatened* (i.e. *Critically Endangered-CR*, *Endangered-EN* and *Vulnerable-VU*) and *Near Threatened-NT*. The IUCN Red List is recognized as one of the most reliable sources of information on the global conservation status of plants and animals (Rodrigues *et al.*, 2006) and classifies species at high risk of global extinction under different categories following well established criteria (IUCN, 2015).

Second, we selected those species included in the IUCN Red List as *Least Concern-LC* but with an index of vulnerability (IV) higher than 60 (i.e. high to very high vulnerability; Cheung *et al.*, 2007). The IV index of a species defines the IV of marine fish to fishing, calculated using a fuzzy logic expert system, and is based on the life history traits and ecological characteristics of marine fish, such as maximum body length, age at first maturity, the von Bertalanffy growth parameter *k*, natural mortality, maximum age, geographical range, fecundity, and the strength of aggregation behaviour (Cheung *et al.*, 2005). Generally, the most vulnerable fish are deemed to be species with larger body size, higher longevity, higher age at maturity, lower growth rates, a low reproductive potential, and a narrow geographical range. These IV values were obtained from the FishBase platform (Froese and Pauly, 2016; http://www.fishbase.org/) in the case of fish, and from the SealifeBase platform (http://www.sealifebase.org/) for organisms other than fish. Third, we included in the selection of vulnerable exploited species three decapod species (*Homarus gammarus*, *Scyllarus arctus*, and *Scyllarides latus*) which, despite being on the IUCN Red List as *Least Concern* or Data Deficient and having an IV index lower than 60, were nevertheless included in the Barcelona, Bern, and CITES conventions, and/or in the EU Habitats Directive.

In addition, for SSF and RF, we computed the mean IV index of the overall catch (weighted mean IV index) by gear, when catch data were available by gear. The weighted mean IV index gives a measure of the vulnerability of the overall catch (Cheung *et al.*, 2007; Font and Lloret, 2011; Lloret and Font, 2013) and was calculated from the arithmetic mean of the IV index of each taxon weighted by its catch (see previous section and

Supplementary Table SB2). The mean IV of the catch ranges from 1 to 100 and a higher value represents greater vulnerability.

In coastal waters, the weighted mean IV index could be computed in only nine of the study areas because information on catches in other areas was incomplete. Regarding offshore fisheries, the mean IV of the overall catch was computed without taking into account the fishing gear (because catch data were not available by gear).

Vulnerability of the bycatch

The vulnerability of the species in the bycatch was also evaluated. In this study, bycatch refers to all unintentional catch returned to the sea for whatever reason (unwanted, unsellable, or impermissible). Existing information about the bycatch of vulnerable species caught by SSF and RF in the Mediterranean coastal and offshore waters was gathered from scientific papers and reports available in the literature. This review of the bycatch focused on vertebrates, including marine birds, elasmobranchs, and marine mammals that are categorized in the IUCN Red List as Near Threatened or higher, or listed in the Habitats Directive or in international conventions for the protection of the flora and fauna (Barcelona, Bern, and CITES). This analysis considers coastal and offshore fisheries together because many bibliographic sources did not distinguish between gears deployed in coastal waters and the gears deployed in offshore waters.

Results

Coastal waters

Taking into consideration all types of SSF and RF, and all coastal water areas reviewed here, a total of 152 different species were caught, 35 of which (i.e. 23% of the total) were deemed vulnerable (Supplementary Table SB2). SSF caught a total of 90 species (73 by trammel net; 61 by gillnet; 36 by longline; and 25 by pound net) of which 26 (29%) were deemed vulnerable. RF caught 136 different species (111 by boat fishing; 102 by shore fishing; and 48 by spear fishing), 29 of which (21%) were deemed vulnerable (Supplementary Table SB2). The fishing methods targeting the highest number of vulnerable species are, in order, trammel net (25 vulnerable species), boat fishing (24), gillnet (17), shore fishing (16), spearfishing (12), longlines (10), and pound nets (7) (Figure 2).

Considering the catch in weight, and taking all fishing methods into account, vulnerable species constituted, by weight, 45.4% of the total SSF catch and 18.5% of the total recreational catch in coastal waters. The proportion of vulnerable species was particularly high in the longline catch, 79% of which comprised vulnerable species (Supplementary Table SB2). For certain fishing methods, there were individual vulnerable species that made up 10% or more of the total catch (Supplementary Table SB2): 54% of the total longline catch consisted of *Conger conger*; 23% of total gillnet catches were *M. merluccius*; 16% of total spearfishing catches were *Epinephelus marginatus;* 13% of the total trammel net catches were *Scorpaena scrofa*; and 10% of the total shore fishing catch was *D. labrax*. Boat fishing and pound nets were the only methods where no individual vulnerable species exceeded 5% of the total catch (Supplementary Table SB2).

Some vulnerable benthic species caught by SSF and RF in coastal waters, such as *Anguilla anguilla*, *E. marginatus, Sciaena umbra*, or *Dentex dentex* were among the most vulnerable in terms of the IV index (>60) and are under threat according to the IUCN Red List (*A. anguilla*: CR; *E. marginatus*: EN; *S. umbra* and *D. dentex*: VU). Furthermore, nine of the coastal species targeted by small-scale and recreational fisheries were included in Annex III of the Barcelona and/or Bern conventions; one species is included in CITES-Annex II (*A. anguilla*) and another (*S. latus*) is included in the Habitats Directive-Annex V.

Of all the fishing methods in use in coastal waters, the mean IVs were highest in the longline and spearfishing catch, with 72.6 and 64.7 (out of 100), respectively; such levels are considered as "high to very high" (Figure 3). The lowest mean IV index was in the pound net catch (38.3; low to moderate vulnerability) while the mean IV index for the catches by the other coastal fishing methods (boat fishing, shore fishing, trammel net and gillnet) ranged from 43 to 51 (moderate vulnerability).

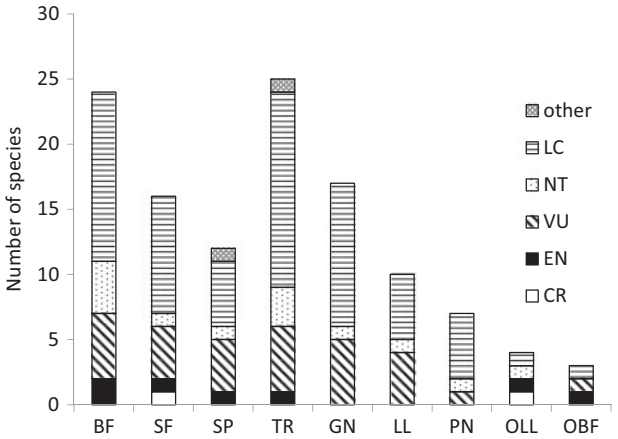

Figure 2. Number of vulnerable species caught by each fishing method operating in coastal and offshore waters. The fishing methods are: Recreational fisheries (BF, boat fishing; SF, shore fishing; SP, spearfishing; OBF, offshore boat fishing) and small-scale fisheries (TR, trammel net; GN, gillnet; LL, longline; PN, pound net; OLL, offshore long line). The vulnerability categories are: LC, least concern with IV >60; NT, near threatened; VU, vulnerable; EN, endangered; CR, critically endangered; Other, species not on the IUCN Red List, but which are included in International Conventions (Barcelona, Bern, and CITES conventions) and/or the EU Habitats Directive.

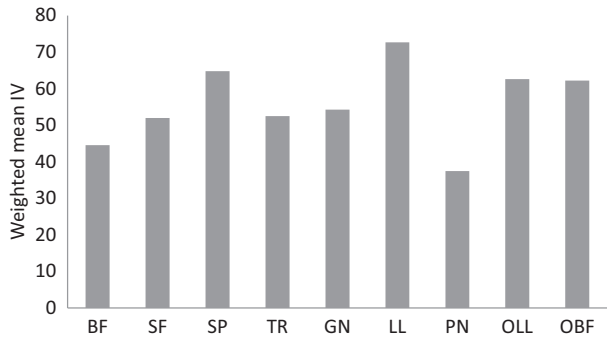

Figure 3. Weighted mean intrinsic IV by fishing method operating in coastal and offshore waters. Recreational fisheries (BF, boat fishing; SF, shore fishing; SP, spearfishing; OBF, offshore boat fishing) and small-scale fisheries (TR, trammel net; GN, gillnet; LL, longline; PN, pound net; OLL, offshore long line).

Offshore waters

In offshore waters, small-scale fishers fishing with pelagic longlines caught four species, *T. thynnus, X. gladius*, *Thunnus alalunga*, and *Prionace glauca*, all of which, again, are vulnerable (Supplementary Table SB2, Figure 2). At the same time, recreational boat fishers caught three species, *T. thynnus*, *T. alalunga*, and *M. merluccius*, all of which are vulnerable (Supplementary Table SB2, Figure 2). In other words, 100% of the offshore SSF and RF catch comprises vulnerable species. In 2017, Spanish recreational boat fishers declared a catch of 0.87 tonnes of *T. thynnus*, 0.75 tonnes of *T. alalunga*, and 0.002 tonnes of *M. merluccius*. Hence, *T. thynnus* and *T. alalunga* are by far the two main constituents of the total offshore recreational catch (99.8%). Also in 2017, Spanish offshore SSF operating with pelagic longlines, landed a total of 1329 tonnes of swordfish (*X. gladius*), 207 tonnes of *T. alalunga*, 32 tonnes of *P. glauca*, and 0.13 tonnes of *T. thynnus*. In this case, 84.8% of the offshore pelagic longline catch consisted of swordfish alone.

These five vulnerable species caught in offshore waters were among the most vulnerable both in terms of their IV values (60 or higher in each case) as well as in their classification in the IUCN Red List, because, with the exception of *T. alalunga*, which is classified as LC, all of these pelagic species are threatened (*T. thynnus:* EN*; P. glauca:* CR) or near threatened (*X. gladius*). Furthermore, *T. thynnus, X. gladius*, and *P. glauca* are included in Annex III of the Barcelona and Bern conventions.

In the case of offshore fisheries, the mean IV index of the SSF catch was 62.58 while that of the RF catch was 62.23, both corresponding to levels considered as "high" (Figure 3).

Bycatch of vulnerable species

Due to a lack of specific data on the methods used, the bycatch of vulnerable species could not, as we mentioned earlier, be analysed separately for coastal and offshore waters. The combined bycatch in both areas by SSF and RF included a total of 27 vulnerable vertebrate species, which are listed in Supplementary Table SB3. Small-scale fishing methods led to the unintended capture of six mammal species, three turtle species, eight elasmobranchs, one osteichthyes, and six different species of seabirds. Longlines (demersal, pelagic, and drifting) were responsible for the highest number of vulnerable species in the bycatch (20 species), followed by driftnets (11), gillnets (8), and trammel nets (8). Meanwhile, RF unintentionally caught eight vulnerable species: three elasmobranchs, one osteichthyes, and three seabirds. The vulnerable species appearing in the bycatch include four elasmobranchs (*Isurus oxyrinchus, Sphyrna zygaena, Lamna nasus*, and *P. glauca*) and one bird (*Puffinus mauretanicus*) that are on the IUCN Red List as critically endangered species. There is also one mammal (*Physeter macrocephalus*) and three sea turtles (*Caretta caretta, Dermochelys coriacea*, and *Chelonia mydas*) which are listed in Annex I of the CITES convention (Annex I lists the most endangered species recorded in CITES records, i.e. those under threat of extinction). In addition, the bycatch includes a number of other chondrichthyans, including *Cetorhinus maximus, S. zygaena, L. nasus*, and *Alopias vulpinus* listed in Annex II of CITES (Annex II lists species that may not, as yet, be under imminent threat of extinction).

Discussion

This article provides new information on the vulnerability of the catch and bycatch associated with recreational and small-scale fisheries operating in coastal and offshore waters in the western Mediterranean Sea. Although generally speaking these fisheries have a smaller ecological impact than large-scale ones (i.e. smaller catches, lower impact on habitats, lower annual fuel oil consumption, less bycatch and discards and less of the catch reduced to fishmeal and oil; Kelleher, 2005; Tsagarakis *et al.*, 2014; Lloret *et al.*, 2018), the results of this study show that they may pose a threat to vulnerable species. In order to identify the vulnerable species among all the species caught, a framework is provided, based on the IUCN Red List, international conventions for the protection of flora and fauna, the Habitats Directive and the IV index of marine fish.

A number of studies in the Mediterranean have already indicated the pressure being placed on particular vulnerable benthic species by coastal small-scale and recreational fisheries (Adbul Malak *et al.*, 2011; Harmelin-Vivien *et al.*, 2015; Marengo *et al.*, 2015; Biton-Porsmoguer, 2017; Biton-Porsmoguer and Lloret, 2018). For example, Marengo *et al.* (2015) found that the combined impact of artisanal and recreational fisheries targeting vulnerable species can have consequences on the *D. dentex* stock in the Bonifacio Strait Natural Reserve. In addition, the status of the main large pelagic species fished offshore, such as *X. gladius* and *P. glauca*, shows clear signs of overexploitation (Biton-Porsmoguer, 2017; Biton-Porsmoguer and Lloret, 2018).

Our results also highlight the need to differentiate between different fishing methods or gears when studying the fishing impacts, because the small-scale fishing fleets and recreational fisheries in the western Mediterranean comprise many types of gears that catch different vulnerable species. Take, for example, the weighted mean IVs for the longline catch (73) and the spear fishing catch (65) in coastal waters, and the catches made by recreational boat fishing (62) and professional pelagic longlines (62) in offshore waters. These values are higher than the mean IV index of the catches made by the rest of fishing gears studied and far exceed the mean vulnerability index of all world-wide exploited coastal fish species (which stands at 48 according to Cheung *et al.*, 2007).

The particular effects of spear fishing on some vulnerable species in the Mediterranean have been already reported in a number of studies (Coll *et al.*, 2004; Rocklin *et al.*, 2011; Harmelin-Vivien *et al.*, 2015; Lloret *et al.*, 2018). For example, Harmelin-Vivien *et al.* (2015) showed how spear fishing contributed to the decline of the brown meagre (*S. umbra*) population in the MPA of Scandola (Corsica) whereas Rocklin *et al.* (2011) demonstrated that spear fishing in the MPA of Bonifacio Strait can modify species assemblage structure. Despite the potential threats posed by spear fishing to vulnerable species, recent studies found that when humans behave like a typical predator, as occurs during spear fishing, fish are able to learn about them, and this may offer an advantage to exploited species to adapt to fishing pressure (Meekan *et al.*, 2018).

It must be noted, however, that it is not only the fishing method (small-scale, recreational, boat, shore, etc.) that may cause more or less important impacts on resources and vulnerable species, but also the fishing gear used within each method (e.g. trolling, bottom fishing, jigging, spinning, trammel net for cuttlefish, trammel net for red mullet, etc) all of which may have

different impacts. Although we did not have the data classified by gear, it would be advisable in future monitoring programmes to collect the information by fishing gear/method in order to identify which fishing types and methods have the greatest impact, in order to establish more gear-oriented restrictions and management actions.

In addition, this study has highlighted the fact that there were many vulnerable species of mammals, elasmobranches, turtles and birds caught as bycatch by small-scale and recreational fishing gears in coastal and offshore waters. These species are listed in the various annexes of the Habitats Directive and Birds Directive, which represent greater protection needs than the international conventions for the protection of biodiversity (i.e. Barcelona, Bern, Bonn, CITES), the IUCN Red List and/or the EU Habitats Directive. SSF are responsible of the largest number of species in the bycatch, with trammel nets and driftnets being the fishing gears that unintentionally catch the greatest number of vulnerable species.

Elasmobranchs are a group of fish that appear in both the list of target and bycatch species caught by recreational and small-scale fisheries operating in coastal and offshore waters, which present an array of challenges for fisheries management and conservation (Fowler *et al.*, 2005; Gibson *et al.*, 2008). They are generally vulnerable to fishing because of peculiar characteristics of their life cycle (low fertility rate, slow growth, and late maturity; Dulvy *et al.*, 2003; Gibson *et al.*, 2008). As a result, these species, which play a key role in maintaining the balance in marine ecosystems (Ferretti *et al.*, 2010), have a generally limited capacity to restore their population and consequently can be more easily endangered by fishing (Fowler *et al.*, 2005; Gibson *et al.*, 2008). For example, recent studies highlight the current population decline—or even, in some cases, local extinction—of several elasmobranchs in waters around the Balearic Islands, where they had previously been quite common (Mayol *et al.*, 2000; Ferretti *et al.*, 2008; Ligas *et al.*, 2013; Grau *et al.*, 2015; Farriols *et al.*, 2017). Similar rarefactions have also been documented in other Mediterranean areas (Maynou *et al.*, 2011; Ligas *et al.*, 2013; Coll *et al.*, 2014) and in other seas and oceans (Ferretti *et al.*, 2008).

Mediterranean fisheries are expected to continue to exert a significant impact on vulnerable target and bycatch species in the foreseeable future, but the scale of the impact will be different for each sector. For SSF, the impact will remain high but possibly decreasing in many coastal areas if the recent decline observed in SSF continues in the coming years (Lloret *et al.*, 2018). In contrast, it appears that the impact on vulnerable species by RF will continue to rise with increased activity from this sector reported not only in coastal waters (Lloret *et al.*, 2018), but also in offshore waters, where considerable growth in the number of sport fishers has been observed over the past few years off the Italian, Spanish and French coasts. For example, the number of Spanish recreational boats with special authorization to fish large pelagic fish species in the Mediterranean increased between 2015 and 2017, from 661 to 917. The data analysed in this article suggest that, in offshore waters, the current impact of small-scale fisheries (SSF) is much higher than that of recreational fisheries (with the SSF catch of pelagic species being several times higher in comparison). Despite this, the impact of each sector in coastal waters has been found to be similar in some areas such as, e.g. in the MPA Cap de Creus (Lloret *et al.*, 2008).

It is imperative that monitoring and assessment plans for all these vulnerable species are developed and carried out. Studies on the status of these species are needed to better understand the impact exerted on them by recreational and small-scale fisheries, given the lack of data and assessments of most of the vulnerable target and bycatch species in the Mediterranean. In this sense, the impact on survivability/mortality of vulnerable target and bycatch species caused by fishing should be assessed for the various types of fishing gear and methods currently being employed. Given that, for most of these species, there is a lack of specific studies determining the status of their population and the impact of fisheries on them, the conclusions from this study must be taken with caution. The problem with the lack of accurate, gear-specific data is of particular concern in the case of offshore recreational fisheries, especially with regard to bycatch. It is also important to carry out new studies that evaluate the effect of certain features of the MPAs, such as the level of protection and efficiency of enforcement and the number of years in operation, on the catch of vulnerable species in order to better understand the effects of these fisheries under different circumstances.

The findings of this study should help to provide basic guidelines for both managers and policy makers in their work to develop specific management measures that will ensure the protection of vulnerable species caught by small-scale and recreational fisheries in the western Mediterranean Sea, while safeguarding small-scale fisheries in accordance with the FAO guidelines on SSFs (FAO, 2015) and ensuring the sustainability of recreational activities, which are becoming increasingly important in the economies of a number of Mediterranean countries (Lloret *et al.*, 2018). These measures, based on the precautionary principle, could include reducing the fishing pressure on certain vulnerable species (e.g. by regulating fishing gears and baits) or, in some cases, prohibiting their capture, at least in specific areas, such as MPAs, and/or in particular seasons of the year. A number of studies have demonstrated the valuable role played by Mediterranean MPAs, particularly under certain circumstances (e.g. sound protection of habitats and species, strong enforcement of laws, optimal size, etc) in protecting and rebuilding the populations of vulnerable species (Harmelin-Vivien *et al.*, 2015; Giakoumi *et al.*, 2017; Di Franco *et al.*, 2018), and that seasonal closures during the reproductive season are effective in the protection of spawning aggregations of vulnerable species (Sadovy de Mitcheson *et al.*, 2013). Furthermore, minimum landing sizes should be implemented for all vulnerable species, whereas maximum landing sizes should be also implemented for sex-changing species such as *E. marginatus, Pagrus pagrus*, and *Labrus viridi*s in order to preserve their reproductive potential (Lloret *et al.*, 2012). In light of recent evidence of strong competition between illegal and legal fishing (by both professional and recreational fishers) in the Mediterranean Sea (Ben Lamine *et al.*, 2018), it is also paramount to combine protective measures with an effective enforcement (Sadovy de Mitcheson *et al.*, 2013), and to promote greater public awareness, which can lead to support for legislation and action at the consumer end of the supply chain by empowering customers to make better seafood choices, e.g. by avoiding the consumption or the catch of vulnerable species. In this sense, public awareness will contribute to the so-called "rewilding" initiatives, which are emerging as a promising restoration strategy in a human-dominated world to promote self-sustaining ecosystems and enhance the conservation status of biodiversity (Torres *et al.*, 2018). Finally, technical solutions aimed at avoiding/minimizing bycatch are needed to avoid the catch of vulnerable elasmobranchs, sea birds, mammals and turtles, including the

prohibition of fishing in particular areas and seasons in which these animals appear in greater abundance.

These protective measures are not only necessary to safeguard vulnerable species from overfishing or extinction, but are also important in ensuring the FCS of SACs, which are strictly protected sites designated under the EU Habitats Directive in European waters. The vulnerable species affected by small-scale and recreational fisheries in coastal waters of the Mediterranean inhabit different habitats included in this Directive, such as *Posidonia* meadows and coralligenous assemblages. The protection of vulnerable species that are typical in these habitats is necessary to attain the desired FCS in European waters.

In some cases, the EU, national and/or regional managers have already begun to implement rules to protect vulnerable species from overfishing, enabling certain populations to recover—although such measures remain somewhat limited, particularly in coastal waters. For example, in French Mediterranean coastal waters (excluding Corsica), there is a ban on recreational hook and line fishing and spear fishing for brown meagre (*S. umbra*), and a ban on professional and recreational hook and line fishing and spear fishing for groupers (*Epinephelus* spp. and *Mycteroperca rubra*), until at least 2023. However, small-scale fishers can fish brown meagre and groupers with nets. Also, recreational fishers are not allowed to catch the vulnerable decapods *Palinurus elephas* and *S. latus* in Spain, nor *S. latus* in France and Italy (furthermore, professional fishers in France are not allowed to catch *S. latus*). In Italy, it is forbidden to fish mature female of *P. elephas* and *H. gammarus* by any recreational fishing method, and any crustacean with spearfishing. Although there is very little published information on illegal fisheries, there are, nevertheless, indications that poaching does occur; for example, in the MPA of Calanques (France), poachers are reported to be targeting the larger, older females of two protected species, the dusky grouper (*E. marginatus*) and the brown meagre (*S. umbra*) (Astruch *et al.*, 2018).

In offshore waters, some legislative measures to protect vulnerable species are also in place. France for example has forbidden the on-board presence, landings and sale of swordfish by recreational fisheries (although catch and release is allowed in particular months). Also in France, the recreational fishing of *T. thynnus* requires a special authorization. Restrictive measures in France affect other pelagic vulnerable species, such as *Raja undulata*, fishing of which is forbidden. In Spain, recreational fishers cannot fish for pelagic sharks, such as *P. glauca*, although they have no obligation to report bycatch. As with recreational fisheries, the commercial fisheries of large pelagic fish are often regulated by specific national regulations. For example, in Spain, professional fishers are obliged to request specific authorization, and a catch and release declaration must be completed. Furthermore, protective measures have been established for several large pelagic vulnerable species that can be caught by recreational fisheries, including *T. alalunga, T. thynnus, Thunnus obesus, Makaira spp., Tetrapturus spp., Istiophorus albicans*, and *X. gladius*. Other regulations have also been established by the European Commission, banning the catch, trade or landing of several shark species, including *C. maximus*, *S. zygaena, L. nasus*, and *A. vulpinus*, by recreational and professional fisheries. Furthermore, the EU, in the case of recreational fisheries, authorizes the catch of only one individual swordfish per day and boat, with a minimum fork length of 100 cm or a minimum weight of 10.2 kg. Furthermore, the EU has banned the fishing of certain shark and elasmobranch species for all professional and recreational fishing fleets, while fishing for *T. thynnus* and *X. gladius* in the Mediterranean by small-scale fisheries is subject to closed seasons and quotas established by ICCAT in all contracting countries. Finally, some of the large vulnerable pelagic species such as bluefin tuna and swordfish are subject to recovery plans that establish specific measures for small-scale and recreational fisheries throughout the Mediterranean or in certain specific areas. Finally, it must be pointed out that although this analysis provides a general picture of the potential impact of recreational and small-scale fisheries on vulnerable species, there are still some uncertainties regarding the results. For example, the fact that marine recreational fisheries in Europe are usually subject to different national, regional, and MPA legislation results in different restrictions on fishing methods and techniques (e.g. spear fishing is not allowed in a number of MPAs), different total catch limits for certain species, and different species authorized for catch; this, in turn, produces uncertainty with respect to the harvested biomass. Furthermore, the fact that the recreational fishing surveys are mostly carried out during the summer season may lead to an underestimation of the impact of recreational fisheries on species that tend to be caught during the winter season, such as *D. labrax*.

In short, the results from this study indicate that, despite the fact that recreational and small-scale fisheries in the western Mediterranean are often considered "low impact fisheries" compared with other larger-scale fishing methods, such as trawling and purse seining, they may still pose a threat to vulnerable species, whether they inhabit coastal or offshore waters, and whether they are targeted and commercialized, or unintentionally taken as bycatch and discarded. This threat may very well compromise the conservation of these vulnerable species—as well as the fisheries associated with them—if urgent and effective management actions (e.g. implementation of new fishing bans and minimum and maximum landing sizes; establishment of closed seasons, etc.) are not undertaken to protect them.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

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