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Updating the national checklist of marine fishes in Spanish waters: An approach to priority hotspots and lessons for conservation

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Abstract

In response to a request from the Spanish Ministry of Farming, Fishing, Food, and Environment (Spanish: *Agricultura, Pesca, Alimentación y Medio Ambiente*) in 2015, a fish expert group was formed to provide a reference list of marine fish species according to five regions (marine demarcations) established by Spanish Law 41/2010 on the protection of the marine environment. The objective of this article was to update and analyse the data compiled in the marine fish species checklist in order to: 1) provide a complete list of marine fish species in the Spanish Exclusive Economic Zone; 2) compare this checklist between bio-geographical areas; and 3) identify possible priority hotspots for their conservation. We applied several indices, such as the total number of species in each area, species richness, and the Biodiversity Conservation Concern index. We discuss gaps in knowledge and the lessons learned for conservation purposes. A total of 1075 marine fishes were reported in Spanish waters. Most of these fish were well determined, whereas a few were treated as uncertain. The marine demarcation with the most species is the Canary Islands with 795 species, followed by the Spanish north coast demarcation with 506 species. However, the marine demarcations with the most species per area are the Spanish coast of the Gulf of Cádiz and the Strait of Gibraltar-Alboran Sea.

Keywords: Marine fish; biodiversity; conservation.

Introduction

The term “pisces” (fishes) refers to animals traditionally included in a superclass category, currently considered to be a typological classification, but not a phylogenetic one. Fish are typically ectothermic aquatic vertebrates that vary their body temperature as ambient temperatures change, although some pelagic scombrids

(Scombridae), sharks (Lamnidae), and swordfish (Xiphiidae) have partial endothermia. Most fish are covered by scales and are equipped with fins and gills with which to swim and breathe, respectively. Fish make up more than half of the approximately 60,000 known vertebrate species. Some 35,025 valid fish species have been described in comparison to 28,000 tetrapods (Nelson *et al.*, 2016; Fricke *et al.*, 2019). In European waters, about 1300 fish

species have been recorded, which include Agnata (5), Chondrichthyes (145), and Osteichthyes (1199) (Costello *et al.*, 2001; Nieto *et al.*, 2015).

The first Spanish ichthyological writings date back to the 18th century. Pehr Löfving, a Swedish botanist and Carl Linnaeus' follower, wrote an unpublished manuscript in 1753 (Löfving, 1753) listing about 95 fish species of Andalucía (southern Spain) (de la Torre & Arias, 2012). Subsequently, Cornide (1788) published a list of marine fauna in which he recorded approximately 65 species of marine fishes of Galicia (northwest Spain). A year later, Medina Conde (1789) recorded the common names of 293 fish and the scientific names of 63 fish, molluscs, crustaceans, and coelenterates of Málaga (Andalucía, Spain) (<http://www.ictieterm.es/>). More recently, Lloris (2015) reported that there were 954 known fish species in the Spanish waters of the Iberian Peninsula and Balearic Islands, while Brito *et al.* (2002) and Falcón (2015) recorded 691 and 778 species in the Canary Islands, respectively.

In May 2015, the Spanish Ministry of Farming, Fishing, Food, and Environment convened several groups of experts on different taxonomic groups (crustaceans, mollusca, fishes, etc) to create a Reference List of Marine Species (RLOMS). This project was implemented in response to a legal commitment to comply with the requirements of the Marine Strategy Framework Directive (MSFD) of the European Union (EU, 2008; Bellas, 2014) regarding descriptor 1: Biodiversity. This initiative is part of the Spanish Inventory of Habitats and Marine Species (Spanish acronym: IEHEM) (Gofas *et al.*, 2017).

In line with the request from the Ministry, the main objective of the fish expert group was to provide a reference list of marine fish species based on the five regions (marine demarcations) established by Spanish Law 41/2010 on the protection of the marine environment (LPME) according to the standard process of transposing the MSFD into Spanish national law (BOE, 2010).

The RLOMS has recently been published in the Spanish Official State Bulletin (BOE, 2017) according to the resolution of February 17, 2017 from the Secretary of State for the Environment. Checklists of marine fish species from Spanish jurisdictional waters already exist; however, the majority of them only cover specific local areas, such as the Canary Islands (Brito *et al.*, 2002), the Balearic Islands (Mayol *et al.*, 2000), the Catalan Sea (Lloris *et al.*, 1984), Galician waters (Bañón *et al.*, 2010; 2016), and the Cantabrian Sea (Sánchez *et al.*, 2002), among others. Thus, the current RLOMS represents the first attempt to combine and compile all the published information and new data to provide a complete updated review of marine fish species in Spanish waters.

At present, there is a growing interest in the detection of priority areas for the conservation of biodiversity, which are known in the scientific literature as “hot spots” (Fattorini, 2006; Fattorini *et al.*, 2012). For this reason, several standardized indexes have been developed to assess hot spots and evaluate whether they have been correctly designated as such (e.g. see Berguerot *et al.*, 2008).

The main aim of the current study was to review, im-

prove, and update the previous checklist of marine fish species in the Spanish Exclusive Economic Zone (Spanish acronym: EEZ) reported by the Spanish Ministry of Farming, Fishing, Food, and Environment. The second aim was to analyse the data compiled in the marine fish species checklist, compare this checklist between bio-geographical areas, and identify possible priority hotspots for their conservation.

Material and Methods

Study area

The scope of the marine checklist includes all Spanish jurisdictional waters, including Canarian and Balearic waters within the limits of the EEZ. The list includes all local fish species (including endemic species) inhabiting shallow to abyssal waters as well as highly migratory species.

According to the requirements of the MSFD, which were transposed into Spanish law (BOE, 2010), the Spanish government established five regions or marine demarcations. With the aim of management and conservation, these demarcations were based on biogeographic, oceanographic, and hydrological characteristics. Further details on the five marine demarcations are provided in Suarez de Vivero & Rodríguez Mateos (2012) and Bellas (2014). In this study, we use demarcations as operational units because these areas will determine the management and conservation policies of the Spanish government in the coming years.

The Atlantic region includes three demarcations: the North Atlantic (NOR, Spanish north coast), the South Atlantic (SUD, Spanish coast of the Gulf of Cádiz), and the Canary Islands (CAN, the Canary Islands). The Mediterranean region comprises two demarcations: the Levantine-Balearic (LEBA, East coast of Spain and Balearic Islands) and the Strait of Gibraltar and Alboran Sea (ESAL) (Fig. 1).

Thus, the RLOMS compiled information on these five marine demarcations. As reported by other authors, the size of the demarcations is unequal: NOR, 306499 km²; SUD, 14978.3 km²; ESAL, 25852.9 km²; LEBA, 232642 km²; and CAN, 486195 km² (Gofas *et al.*, 2017). These demarcations include a rich diversity of habitats including shallow coastal waters, detritus bottoms, steep coastal waters, and maërl beds (for a complete list of habitats by demarcation and a detailed description of these habitats, see Templado *et al.*, 2012).

Database

The main source of the records was based on the lists of species observed in the annual research surveys conducted by the Spanish Institute of Oceanography (IEO) in different geographical areas. In the case of the CAN demarcation, the main sources were Brito *et al.* (2002) and Falcón (2015). Additional information was also in-

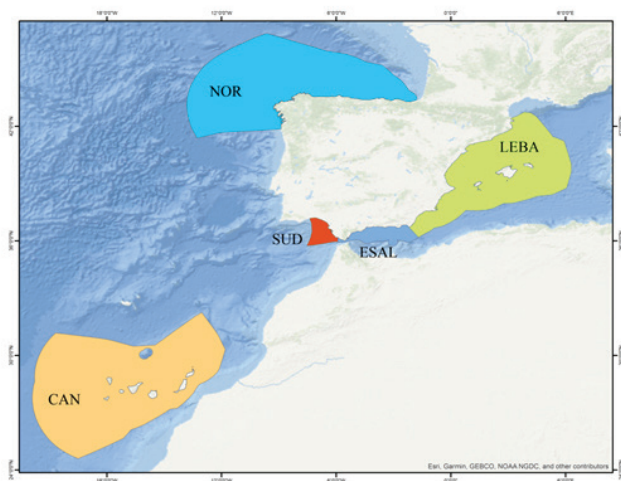


Fig. 1: The Spanish marine demarcations with their limits. Key: NOR (light blue), Spanish north coast; CAN (orange), the Canary Islands; SUD (red), Spanish coast of the Gulf of Cádiz; ESAL (blue), Strait of Gibraltar and Alboran Sea; LEBA (green), East coast of Spain and the Balearic Islands. Source: Instituto Español de Oceanografía.

cluded on fish species recorded in the framework of the INDEMARES project “Inventory and designation of marine Natura 2000 areas in Spanish waters” (INDEMARES-LIFE, 07/NAT/E/0007). This project addressed the protection and sustainability of biodiversity in Spanish waters through the identification of high-value areas for the Natura 2000 marine network (www.indemares.es). In this project, the Spanish Ministry proposed 11 areas for their designation as a Special Area of Conservation (SAC) for species and habitats, under the Habitat Directive (Council Directive 92/43/EEC), and as part of the Natura 2000 network of marine protected areas (MPA) in the North East Atlantic Ocean. Previously, relevant contributions on the deep-sea fish of the Cantabrian Sea were provided by studies conducted by the ECOMARG project in Le Danois Bank that gave rise to the creation of the first Spanish MPA included in both the RN2000 and the OSPAR Convention (biodiversity list on www.ecomarg.com, Sánchez *et al.*, 2008).

Furthermore, we actively searched new records and recently updated citations for each record considered as dubious. Regarding taxonomic nomenclature, we followed Eschmeyer *et al.* (2018) to the species level and Nelson *et al.* (2016) to the order and family levels. After this thorough revision, all fish species in each area were categorized as P (Present) or R (Revisable). “Present” refers to species for which there is evidence (survey data, published literature, and collections) of its presence in the demarcation. “Revisable” refers to species that are occasionally misidentified due to taxonomic problems with similar species, or that have been previously cited in demarcations without an exact location, are rarely observed, or are very sporadic.

Data analysis and ecological indices

We calculated the total number of species in each area (S) and the Margalef (d) index. The Margalef (d) index is represented by the expression:

$$d = (S-1)/\text{Log}(N);$$

where S is the number of species in each area and N is the total number of species.

Similarity between marine demarcations was calculated using Jaccard’s index of similarity, which is particularly recommended for presence and absence data (Real & Vargas, 1996). Subsequently, we constructed a dendrogram by employing the unweighted pair group method with arithmetic mean (UPGMA) clustering method using PAST software (Hammer *et al.*, 2001).

Biodiversity Conservation Concern

The Biodiversity Conservation Concern (BCC) index was used with the aim of prioritizing the conservation of specific areas (Fattorini, 2006). The BCC assesses the conservation status of each demarcation according to the vulnerability of the species that inhabit them (Berguerot *et al.*, 2008).

The BCC index combines the conservation status of each of the species present in each area and the total species richness by area. This index was first described according to the expression:

$$BBC = \frac{\sum_{i=1}^k \frac{\alpha_i A_i}{N} - 1}{\alpha_{\max} - 1}$$

where α_i is the threat weight i assigned to the category, A_i is the number of species included in category i , N is the total number of species, and k is the number of extinction risk categories (Fattorini, 2006).

The degree of concern for each of the species was assessed using the International Union for the Conservation of Nature (IUCN) Red List for Europe (IUCN, 2018), and in the absence of data we used the global assessment. Following the IUCN criteria, five categories were assigned to all fish species recorded in each area: A5 = critically endangered (CR); A4 = in danger of extinction (EN); A3 = vulnerable (VU); A2 = near threatened (NT); and A1 = least concern (LC). The other two categories included in the IUCN - data deficient (DD) and not evaluated (NE) - were also considered in the species list but excluded from the index estimation. The weight factor α_i assigned to each category was that proposed by Fattorini (2006) where $\alpha_5 = 16$, $\alpha_4 = 8$, $\alpha_3 = 4$, $\alpha_2 = 2$, and $\alpha_1 = 1$ for each category, respectively.

The BCC index varies between 0 when no species analysed is threatened and 1 when all species analysed are in the category of highest concern (Berguerot *et al.*, 2008).

Finally, to compare the BCC index between areas, the BCC index obtained in the different marine demarcations was divided by the surface area of each demarcation, as proposed by Meléndez *et al.* (2015).

Results

A total of 1075 marine fishes were reported in Spanish waters. Although this total includes 32 dubious records by demarcation, all species are present in at least one demarcation (SS1). The CAN demarcation has the most species (795 species), followed by NOR (506) species. However, the marine demarcations with most species per area are SUD and ESAL (Table 1). The CAN demarcation also has the greatest species richness (d) (Table 1).

A total of 178 species share all the demarcations. The Families with more fish species distributed in all the demarcations are Sparidae (17 species) followed by Carangidae (8 species) and Rajidae (7 species).

Taking all demarcations into account, the species belong to 61 orders and each demarcation has an average of 52 orders. The most relevant taxonomic groups in terms of the number of species are the orders Gadiformes, Gobiiformes, Myctophiformes, Perciformes, Pleuronectiformes, Scombriformes, Scorpaeniformes, Spariformes, and Stomiiformes (Fig. 2). However, there are marked differences between demarcations. The largest groups in the CAN demarcation are Stomiiformes, Myctophiformes, and Anguliformes, the largest groups in LEBA are Gobiiformes, Gadiformes, and Pleuronectiformes, and the largest group in SUD are Spariformes (Fig. 2).

The similarity index showed that the CAN demarcation is by far the most diverse in terms of species (68% dissimilarity), whereas the two Mediterranean demarcations (ESAL and LEBA) have the highest similarity value (80%) (Fig. 3). The majority of the listed species that contributed the most to the CAN dissimilarity values versus other areas were mesopelagic or bathyal.

Of the 795 fish species registered in the CAN demarcation, nearly half (364) have no record of being found in peninsular waters. The families that contributed the most to this difference were Stomiidae, Myctophidae, Macrouridae, Melamphidae, Paralepididae, Alepocephalidae, Carangidae, Gobiidae, Gonostomatidae, and Muraenidae. In particular, the Stomiidae family accounted for a total of 61 species recorded in all areas, with 51 species only recorded in the CAN demarcation. Only two species (*Stomias boa*, Risso, 1810 and *Chauliodus sloani*, Bloch & Schneider, 1801) in this family were found in all demarcations. The case of the Myctophidae family is similar: a total of 65 species were recorded in all areas, with 38 recorded only in the CAN demarcation. Three species (*Cerastocopelus maderensis* (Lowe, 1839), *Lobiancha*

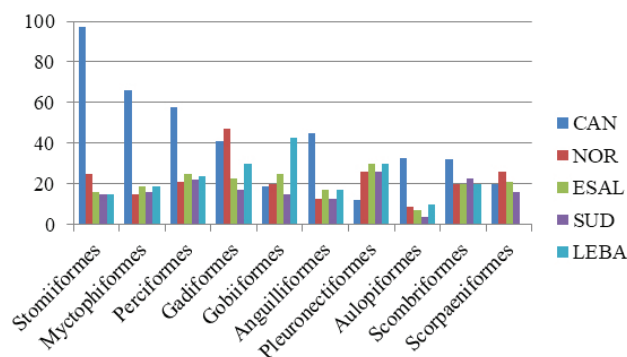


Fig. 2: The most relevant taxonomic groups (orders) according to the number of species in each one by marine demarcation.

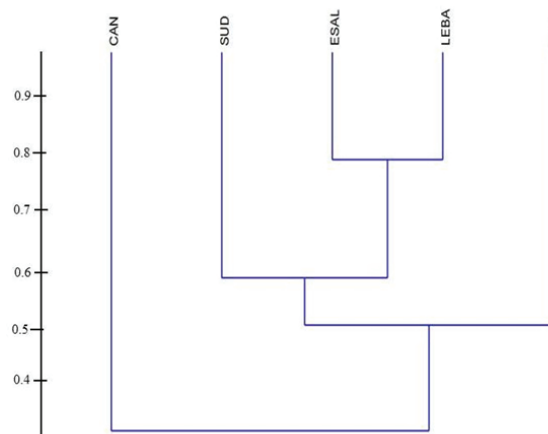


Fig. 3: Cluster of similarity between the marine fish species found in the five demarcations.

gemellari (Cocco, 1838) and *Myctophum punctatum* Rafinesque, 1810 were found in all five demarcations. In contrast, two Myctophiids, *Notoscopelus kroyeri* (Malm, 1861) and *Benthosema glaciale* (Reinhardt, 1837), were found in all areas except in the CAN demarcation.

As mentioned, the highest similarity value (80%) was found in the ESAL and LEBA demarcations, which shared 423 species. Of the recorded species, 36 were only found in these two demarcations. Most of these 36 species were endemic and within the families Gobiidae (8 species) and Blenniidae (4 species). However, three Labridae species, such as *Symphodus doderleini* Jordan, 1890, *S. melanocercus* (Risso, 1810) and *S. rostratus* (Bloch, 1791), sturgeon *Acipenser sturio* Linnaeus, 1758,

Table 1. Number of species, species richness (d), area size, and species/area for each demarcation. Key: CAN, the Canary Islands; NOR, Spanish north coast; SUD, Spanish coast of the Gulf of Cádiz; ESAL, the Strait of Gibraltar and Alboran Sea; LEBA, East coast of Spain and the Balearic Islands.

Demarcation	Number of Species	Species richness (d)	Area (Km ²)	(Species/Area) *100
CAN	795	261.9	486195	0.164
NOR	506	166.3	306499	0.165
SUD	397	130.6	14978	2.651
ESAL	464	152.7	25853	1.795
LEBA	498	164	232642	0.214

Table 2. Number of species per each IUCN category recorded by demarcation. Key: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD), and Not Evaluated (NE). Demarcations: CAN, the Canary Islands; NOR, Spanish north coast; SUD, Spanish coast of the Gulf of Cádiz; ESAL, the Strait of Gibraltar and Alboran Sea; LEBA, East coast of Spain and the Balearic Islands.

IUCN category	All demarcations	NOR	SUD	ESAL	LEBA	CAN
CR	13	9	10	13	13	9
EN	22	18	13	14	15	15
VU	26	14	12	14	16	21
NT	30	25	21	20	20	23
NE	25	13	4	11	17	8
LC	753	331	266	314	338	577
DD	206	96	71	78	79	142
Total	1075	506	397	464	498	795

and some chondrichthyan species, such as *Carcharhinus altimus* (Günther 1870), *Mustelus punctulatus* Risso, 1827, *Dasyatis tortonesei* Capapé, 1975, *Raja polystigma* Regan, 1923 and *Squatina aculeate* Cuvier, 1829 were also found.

Nearly the same number of species (32) were recorded in Mediterranean waters and in the CAN demarcation, but not in the NOR or SUD demarcations. This finding was mainly due to the absence of some labridae such as *Lappanella fasciata* (Cocco, 1833), *Symphodus mediterraneus* (Linnaeus, 1758), *Thalassoma pavo* (Linnaeus, 1758), and *Xyrichtys novacula* (Linnaeus, 1758) as well as some Anguilliformes, Myctophiformes, and Beloniiformes.

Species similarity was 60% for those recorded in the SUD, ESAL, and LEBA demarcations with 305 species in common. Only 21 of these species were exclusive to these demarcations. A total of 114 species contributed to dissimilarity between both Mediterranean demarcations and the SUD demarcation. These species belonged to 33 orders, the majority of which comprised Labriformes with 13 species and Gobiformes with 11.

Table 2 shows the number of species per each IUCN category recorded by demarcation. According to the BCC indexes, the order of priority in the conservation of demarcations should be ESAL (0.120), LEBA (0.117), SUD (0.105), NOR (0.092), and CAN (0.047). However, if we average according to the surface area of each demarcation, the order of priority is SUD (7.0103×10^{-6}), ESAL (4.64×10^{-6}), LEBA (5.029×10^{-7}), NOR (3.0016×10^{-7}), and CAN (9.67×10^{-8}). The change in the first position is due to the fact that although SUD has a large BCC index the demarcation is relatively small.

Discussion

The Canary Islands demarcation

The CAN demarcation is by far the one with the most fish species and the greatest diversity. In contrast, the two Mediterranean demarcations have the most species in

common. Similar results have been found in relation to marine Mollusca (Gofas *et al.*, 2017).

The geographic location of the CAN demarcation and its lack of a continental shelf likely contributes to its dissimilarity compared to other demarcations. For example, the Stomiiformes and Myctophiformes are mainly pelagic fish living in deep oceanic waters and are widely distributed in all oceans (Nelson *et al.*, 2016). They exhibit great diversity in the CAN demarcation. Moreover, this demarcation is rich and diverse due to the effect of the Canary Current Large Marine Ecosystem on this area (Aristegui *et al.*, 2009; Hernández-Guerra *et al.*, 2017), its geographical position, the great environmental heterogeneity of the archipelago, and the high diversity of habitats (Brito *et al.*, 2001; Falcón, 2015). In fact, species diversity by group (Fig. 2) is far higher in this demarcation than in others, except in the case of Pleuronectiformes. However, according to the BCC index, it is an area of low concern because many species in the area were classified as DD and NE. These results should be interpreted with caution.

The CAN demarcation has three exclusive endemic species not shared with other Macaronesian islands: *Didogobius helenae* Van Tassell & Kramer, 2014, *Nettenchelys dionisi* Brito, 1989, and *Diplecogaster ctenocrypta* Briggs, 1955. On the other hand, the CAN demarcation has endemic species shared with other archipelagos of the Macaronesia Islands (Azores and Madeira) and the Cabo Verde Islands: *Paraconger macrops* (Günther, 1870), *Symphodus trutta* (Lowe, 1834), *Mauligobius maderensis* (Valenciennes, 1837), *Scorpaena canariensis* (Sauvage, 1878), *Didogobius kochi* Van Tassell, 1988, *Gymnothorax bacalladoi* Böhlke & Brito, 1987, *Muraena augusti* (Kaup, 1856), *Diplecogaster pectoralis* Briggs, 1955, *Ophioblennius atlanticus* (Valenciennes, 1836), *Bodianus scrofa* (Valenciennes, 1836), *Similiparma lurida* (Cuvier, 1830), *Mycteroperca fusca* (Lowe, 1838), and *Heteropriacanthus fulgens* (Lowe, 1838). *Canthigaster capistrata* (Lowe, 1838) was also exclusive to this area, but has now been reported in the Strait of Gibraltar (Galleote, 2001; Brito *et al.*, 2007). The CAN demarcation is included in the Macaronesian biogeographic ecoregion

of the Lusitanian province (Spalding *et al.*, 2007, Floeter *et al.*, 2008, Almada *et al.*, 2013) and has few endemic species (Brito *et al.*, 2007). Among the reasons for this are the strong currents driven by the Canary Current with many associated eddies and gyres (Stramma, 1984; Molina *et al.*, 1996; Parilla *et al.*, 2002; Hernández-Guerra *et al.*, 2017). This situation generates genetic flow to the south, given that the main stream flows in this direction, as well as toward the north (Falcón, 2015). Nevertheless, other taxonomic groups, such as Mollusca, have a large number of endemic species (N=127) in the CAN demarcation. These Mollusca mainly comprise gastropods and shallow-water species with poor dispersal mechanisms (Gofas *et al.*, 2017).

The previous checklist (BOE, 2017) included 17 non-confirmed (R) species in the CAN demarcation. We confirmed the presence of 3 of the non-confirmed species that are included in the current updated checklist. Regarding the remaining 14 non-confirmed species, we concluded that the previous records were invalid mainly because of errors related to geographical localization and wrong identification. Other errors may derive from the location of the specimens. For example, species may have been caught by the Canary fishing fleet operating on continental shelf of Africa and then unloaded on the islands. This could explain the presence of *Pristis pectinata* Latham, 1794, *Pristis pristis* (Linnaeus, 1758), *Scyliorhinus canicula* (Linnaeus, 1758), *Scyliorhinus stellaris* (Linnaeus, 1758), *Echinorhinus brucus* (Bonnaterre, 1788), and *Oxyotus paradoxus* Frade, 1929. Similarly, the fleet may have caught species in the open sea very far from the Canary Islands. Again, this could explain the presence of *Sphyrna mokarran* (Rüppell, 1837) and *Istiophorus albicans* (Latreille, 1804). Taxonomic errors were the underlying cause of other invalid records for *Atherina lopeziana* Rossignol & Blache, 1961, *Atherina hepsetus* Linnaeus, 1758, *Solea solea* (Linnaeus, 1758), *Dactylopterus volitans* (Linnaeus, 1758), *Entelurus aequoreus* (Linnaeus, 1758) *Sphyrna lewini* (Griffith & Smith, 1834), and *Raja maderensis* Lowe, 1838. The latter species is currently considered a form of *R. clavata* Linnaeus, 1758 (Ball *et al.*, 2016). In the case of the Canarian demarcation, we emphasise that there is little information on the large area west of 19°W longitude.

Mediterranean demarcations: the Strait of Gibraltar and Alboran Sea and the Levantine-Balearic demarcations

In the ESAL demarcation, Atlantic species such as *Galeus atlanticus* (Vaillant, 1888) and *Squalus megalops* (MacLeay, 1881) converge with boreal species such as *Myxine glutinosa* Linnaeus, 1758. On the other hand, some Mediterranean endemisms are absent, such as *Coelorinchus mediterraneus* Iwamoto & Ungaro, 2002, *Gouania willdenowi* (Risso, 1810), *Paralepis speciosa* Bellotti, 1878, *Pegusa nasuta* (Pallas, 1814), and *Syngnathus tenuirostris* Rathke, 1837, whereas some subtropical species are present, such as *Hyporthodus haifen-*

sis (Ben-Tuvia, 1953) and *Ephippion guttifer* (Bennett, 1831).

In the LEBA demarcation, the Gobiidae family present high species diversity with up to 9 species not shared by other demarcations. In this demarcation, *Bathypterois grallator* (Goode & Bean, 1886) has a very fragmented distribution, and so it could be misidentified. Endemic species are noteworthy. These include *Aphanius iberus* (Valenciennes, 1846), which is an Iberian endemism that typically prefers fresh water, but also inhabits marine areas such as estuaries and the Mar Menor (Crivelli, 2006), and *Nansenia iberica* Matallanas, 1985, which is an Iberian mesopelagic endemism (500-800 m depth) that lives around the Balearic Islands and the Iberian Peninsula.

Around 664 fish species have been recorded in the Mediterranean Sea (Quignard & Tomasini, 2000); thus, the 495 species recognized in this study represent the 82.5% of the total number of fish species identified. According to Quignard & Tomasini (2000), the Mediterranean Sea includes a high percentage of marine endemic species (approximately 8.8%), although Coll *et al.*, (2010) reported a higher percentage (12.6%). In the present study, there were 46 endemic species in the ESAL and LEBA demarcations (9.3%).

The Mediterranean Sea has been identified as the major recipient of exotic species in the world (Streftaris *et al.*, 2005). Nevertheless, only two species recorded in this study could be considered as exotic (Lessepsian species) according to the CIEM Atlas list and previous studies (Ben Rais & Mouillot, 2009; Coll *et al.*, 2010; Golani *et al.*, 2016). These species were *Fistularia commersonii* Rüppell, 1838 and *Lagocephalus sceleratus* (Gmelin, 1789). Seventeen species of Atlantic origin were reported in the Mediterranean.

Atlantic peninsular Spanish coast demarcations: the North and South Atlantic demarcations

Two subtropical species with a distribution on both sides of the Atlantic are found in the SUD demarcation but not in the others. These species are *Chloroscombrus chrysurus* (Linnaeus, 1766) and *Zenion hololepis* (Goode & Bean, 1896). However, some species (*Lappanella fasciata*, *Symphodus mediterraneus*, *Thalassoma pavo*, *Xyrichtys novacula*, and *Sparisoma cretense* (Linnaeus, 1758)) have not been recorded in this demarcation despite being recorded in the adjacent waters of the Mediterranean Sea and the Canary Islands. These species are included within the labriformes group.

Typical cold-water species, such as those belonging to the families Ammodytidae (4 species not shared by other demarcations), Gadidae (7 species not shared by other demarcations), and Pentanchidae (4 species not shared by other demarcations), present high diversity in the NOR demarcation. Gadiformes include many types of commercial fish which despite being found in all oceans are mainly restricted to temperate or colder waters (Cohen *et al.*, 1990). Thus, it is reasonable to assume that more species of this order will be found in the NOR demarcation

followed by the CAN demarcation than in the SUD or ESAL and LEBA demarcations. Some of species of the Clupeidae, Gadidae, and Pleuronectidae families have high commercial importance in Europe. These species include herring *Clupea harengus* Linnaeus, 1758, sprat *Sprattus sprattus* (Linnaeus, 1758), cod *Gadus morhua* Linnaeus, 1758, haddock *Pollachius pollachius* (Linnaeus, 1758), and flounder *Glyptocephalus cynoglossus* (Linnaeus, 1758) although they are not sufficiently abundant to be target fisheries in the NOR demarcation.

Tropicalization process: implication of global warming

The planet is currently undergoing global warming. In response, marine fishes are shifting their distribution, generally to higher latitudes. The presence of an increasing number of warm-water species, mainly from tropical areas, in higher latitudes is known as “tropicalisation” (Lloris, 1986; Cheung *et al.*, 2013). Thus, it is clear that a tropicalisation process is underway in almost all demarcations, as shown by the northward expansion of the range of southern species (Brito *et al.*, 2005; Juárez *et al.*, 2008; Bañón *et al.*, 2017a; Brito *et al.*, 2017; Falcón *et al.*, 2018). Tropicalisation is the most relevant force driving the increase in diversity in the CAN demarcation (Brito *et al.*, 2017). Besides the natural extension of populations, which is mainly due to climate change, the presence of tropical species is favoured by anthropogenic factors such as vessel ballast water, aquaculture, and, to a lesser extent, the aquarium trade; however, the main factor is oil platforms (Brito *et al.*, 2005; Falcón *et al.*, 2015; Triay-Portella *et al.*, 2015; Falcón *et al.*, 2018). The Canary Islands are used as a repair area for these structures, which are slowly towed for hundreds of nautical miles from their places of origin (Falcón *et al.*, 2015). Thus, oil platforms are a highly relevant vector for the introduction of non-native species (Brito *et al.*, 2011; Falcón *et al.*, 2015; Triay-Portella *et al.*, 2015; Pajuelo *et al.*, 2016). This aspect is particularly striking in the case of the *Acanthurus* spp. and other introduced species from American tropical coasts. Nevertheless, there are records of anomalies such as *Neoharriotta pinnata* (Chimaeriformes: Rhinochimaeridae), which is an Eastern Central Atlantic and Indian Ocean species that has been reported in the southern Bay of Biscay (Díez & Mugerza, 2017).

Although the novel occurrence of southern thermophilic species is the most evident “natural” phenomenon related to the increase in ichthyofaunistic diversity, other secondary sources can also be identified. The anomalous presence of boreal species was also reported, such as *Anarhichas denticulatus* Krøyer, 1845 in the Bay of Biscay (Rodríguez-Cabello *et al.*, 2015), the skates *Neoraja caerulea* (Stehmann, 1976) and *Rajella kukujevi* (Dolganov, 1985) also in the Bay of Biscay (Rodríguez-Cabello *et al.*, 2013), *Sebastes mentella* Travin, 1951 in Galician waters (Fernández-Zapico *et al.*, 2012), or *Gadus morhua* in the Balearic Islands (Morey *et al.*, 2012). All these species are likely to be cases of expatriate specimens. Furthermore, species have been introduced from

the western Atlantic, such as *Cynoscion regalis* (Bloch & Schneider, 1801) (Bañón *et al.*, 2017b). Others of Indo-Pacific origin have been introduced through the Suez Canal (Lessepsian species) (e.g. *Fistularia commersoni* Rüppell, 1838) (Sánchez-Tocino *et al.*, 2007) or presumably released from private aquaria, such as *Zebrasoma flavescens* (Bennett, 1828) and *Balistoides conspicillum* (Bloch & Schneider, 1801) (Weitzmann *et al.*, 2015).

Gaps in knowledge

Recent decades have seen an increase in knowledge of the number and distribution of marine fish species in Spanish waters, although some differences by demarcation are evident. This knowledge is affected by human factors, such as the presence or otherwise of expert taxonomists or the investigation effort conducted in each area.

At the scientific level, we should highlight the role played by the LIFE+Indemares project (2009-2014) in most of the Spanish marine demarcations. Studies on the identification of the most representative marine areas in Spain to ensure the protection and sustainable use of biodiversity have led for the first time to the identification of numerous fishes. These are mainly deep-water fishes, such as *Apristurus* species (Rodríguez-Cabello *et al.*, 2014). However, new species have also been recently discovered in Spanish waters. These include *Speleogobius llorisi* Kovačić *et al.*, 2016 (Kovačić *et al.*, 2016), *Protogrammus alboranensis* Fricke *et al.*, 2016 (Farias *et al.*, 2016; Fricke & Ordines, 2017), *Buenia massutti* Kovačić *et al.*, 2017 (Kovačić *et al.*, 2017), *Buenia lombartei* Kovačić *et al.*, 2018 (Kovačić *et al.*, 2018), and *Microichthys coccoi* Rüppell, 1852 (Ordines *et al.*, 2018).

Lessons learned for conservation purposes

The results of the BCC index should be taken with caution, given that some authors have detected bias in the index (Berguerot *et al.*, 2008). In the present study it can be seen that the BCC index penalizes high diversity when there are many species catalogued as being at low risk. However, regarding the number of critically endangered species (CR), the worst areas for the conservation of a species according to the IUCN are the ESAL and LEBA demarcations, which are priority areas. According to the total number of species included in any threatened categories (i.e. Critically Endangered, Endangered, Vulnerable), the demarcation order of priority is CAN (45 species), LEBA (44 species), ESAL (41 species), NOR (41 species), and SUD (35 species). There is a high number of DD and NE species. It is possible that their presence may hide that of endangered species. For this reason, the present results are approximations.

The ESAL and LEBA demarcations have the same ratio of the number of endangered species to the total number of species richness per demarcation. This ratio is somewhat lower in the NOR and SUD demarcations, whereas the CAN demarcation has the lowest ratio.

The Spanish Law 41/2010 on the protection of the marine environment has as its main aim the establishment of priorities for the monitoring and conservation of the marine environment in the five Spanish marine demarcations. Thus, the surface area of marine spaces protected by demarcations should reflect the importance of each demarcation in relation to diversity and the presence of sensitive species. Therefore, the CAN and ESAL demarcations are the highest priority demarcations for fish species conservation.

Shark stocks are decreasing in the Mediterranean Sea (Ferretti *et al.*, 2008). In this sense, the Alboran Sea (ESAL) is a relevant area for sharks (Megalofonou *et al.*, 2005). Moreover, the narrow Alboran demarcation presents the highest BCC values per unit area. In this way, the Alboran Sea could favour the conservation of the Chondrichthyes within an Atlantic-Mediterranean framework. In this regard, the RAC-SPA and the IUCN-Med (UNEP/MAP-RAC/SPA, 2015) have promoted the creation of a multinational marine reserve in the Alboran Sea.

The Alboran Sea is a relevant area for the distribution of many pelagic species, because it acts as the entry point to the Mediterranean from the Atlantic. Furthermore, due to local weather and oceanographic characteristics, there is a coastal upwelling system that increases locally productivity (Camiñas, 1981; Parrilla & Kinder, 1987). Moreover, because of the topography of the seabed, which has an average depth of more than 1000 m, there is a wide variety of habitats despite their small size. We should highlight the fact that the intention is to increase the number of protected marine areas by demarcation rather than to protect the entire area.

Excluded taxa

According to Barros-García *et al.* (2016, 2017), *Gaidropsarus biscayensis* (Collett, 1890) is junior synonym of *G. macrophthalmus* (Günther, 1867), *Gaidropsarus guttatus* (Collett, 1890) is junior synonym of *G. mediterraneus* (Linnaeus, 1758) and *Lepidion eques* (Günther, 1887) is junior synonym of *L. lepidion* (Risso, 1810). For this reason, they were included in the excluded taxa.

Despite old records of *Pristis pristis* around the Balearic Islands, according to Ferretti *et al.* (2016) both *P. pristis*, and *P. pectinata* should be considered extinct in the Mediterranean. Thus, both species were included in the excluded taxa.

Final remarks

The number of fish species is constantly changing on Spanish coasts, as shown by the continuous trickle of previously unreported fishes in these areas. As a consequence, new species have been added during the revision process of this study. These additions include five new species in the NOR demarcation: *Remora osteochir* (Cuvier, 1829) (Echeneidae), *Antigonia capros* Lowe, 1843 (Caproidae), *Hyperoglyphe perciformis* (Mitchill,

1818) (Centrolophidae), *Parapristipoma octolineatum* (Valenciennes, 1833) (Haemulidae), and *Epinephelus costae* (Steindachner, 1878) (Serranidae) (Bañón *et al.*, 2018; Bañón *et al.*, 2019a); eight in the CAN demarcation: *Cirrhitus atlanticus* Osório, 1893 (Cirrhitidae), *Chilomycterus spinosus* (Linnaeus, 1758) (Diodontidae), *Epinephelus adscensionis* (Osbeck, 1765) (Serranidae), *E. faciatus* (Forsskål, 1775) (Serranidae), *Holacanthus africanus* Cadenat, 1951 (Pomacanthidae), *Lutjanus griseus* (Linnaeus, 1758) (Lutjanidae), *Muraena melanotis* (Kaup, 1859) (Muraenidae), and *Mycteroperca tigris* (Valenciennes, 1833) (Serranidae) (Falcón *et al.*, 2018); and one in the SUD demarcation: *Megalops atlanticus* Valenciennes, 1847 (Megalopidae) (Bañón *et al.*, 2019b). Thus, it is difficult to create a definitive checklist, and it should be continually revised.

Supplementary Material

The Supplementary Material includes a large table containing a complete list of the species in taxonomic order with occurrences (SS1).

Every species includes a label (P) for well-determined species and a label (R) for species to be confirmed. These are arranged by marine demarcation (NOR, North Atlantic demarcation; SUD, South Atlantic demarcation; ESAL, Strait of Gibraltar and Alboran Sea demarcation; LEBA, Eastern and Balearic demarcation; CAN, Canary Islands demarcation). All species to be confirmed are present in at least one demarcation.

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