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

J Lloret, S Biton-Porsmoguer, A Carreño, A Di Franco, R Sahyoun, P Melià, Joachim Claudet, C Sève, A Ligas, M Belharet, et al.

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

3

4 Lloret, J.\*, Biton-Porsmoguer, S.; Carreño, A.; Di Franco, A.; Sahyoun, R.; Melià, P.; Claudet, J.;  
5 Sève, C.; Ligas, A.; Belharet, M.; Calò, A.; Carbonara, P.; Coll, M.; Corrales, X.; Lembo, G.; Sartor,  
6 P.; Bitetto, I.; Vilas, D.; Piroddi, C.; Prato, G.; Charbonnel, E.; Bretton, O., Hartmann, V., Prats, L.;  
7 Font, T.

8 Lloret, J., Biton-Porsmoguer, S., Carreño, A., Font, T., J. University of Girona, Faculty of Science,  
9 C/ Maria Aurèlia Capmany 69, 17003 Girona, Catalonia, Spain

10 Prato, G. WWF Italy, via Po 25/C, 00198 Rome, Italy

11 Sahyoun, R. WWF France, 35-37 rue Baudin, 93310 Le Pré Saint Gervais, France

12 Melià, P. & Belharet, M. Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico  
13 di Milano, Italy

14 Di Franco, A., Calò, A. Université Côte d'Azur, CNRS, FRE 3729 ECOMERS, Parc Valrose 28,  
15 Avenue Valrose, 06108 Nice, France

16 Claudet, J.; Sève, C. National Center for Scientific Research (CNRS), PSL Université Paris, CRIOBE,  
17 USR 3278 CNRS-EPHE-UPVD, Maison des Océans, 195 rue Saint-Jacques 75005 Paris, France

18 Ligas, A., Sartor, P. Consorzio per il Centro Interuniversitario di Biologia Marina ed Ecologia  
19 Applicata "G.Bacci", Italy

20 Carbonara, P., Lembo, G., Bitetto, I. COISPA Tecnologia & Ricerca, Stazione Sperimentale per lo  
21 Studio delle Risorse del Mare, via dei Trulli 18/20, 70126 Bari-Torre a Mare (BA) Italy, Italy

22 Coll, M., Corrales, X., Vilas, D. Institute of Marine Science (ICM-CSIC) and Ecopath International  
23 Initiative Research Association (EII), Barcelona, Spain

24 Piroddi, C. Joint Research Centre - European Commission, Unit D.02 Water and Marine  
25 Resources, Via E. Fermi 2749, 21027 Ispra (VA) – Italy

26 Virginie Hartmann and Lea Prats, Réserve Naturelle Marine de Cerbère Banyuls, France

27 Eric Charbonnel and Olivier Bretton: Côte Bleue Marine Park, Observatoire PMCB-plage du  
28 Rouet, 31 Av. J. Bart, B.P 42 ; 13620 Carry-le-Rouet, France

29

### 30 **Abstract**

31 This study evaluates the fishing pressure exerted by the most common recreational and  
32 professional, small-scale fishing practices on vulnerable target and bycatch species in western  
33 Mediterranean coastal waters (less than, approximately, 12 miles from the shore) and offshore  
34 waters (more than, approximately, 12 miles from the shore). By combining multiple data  
35 sources, we assembled a unique dataset on catches at multiple sites in these areas by  
36 recreational (RF) and small scale fisheries (SSF), covering the period from 1997 to 2015.  
37 Furthermore, a framework with which to identify the vulnerable species among all the species  
38 caught is provided; it is based on the IUCN Red List, international conventions for the protection  
39 of flora and fauna, the Habitats Directive and the intrinsic vulnerability index of marine fish.  
40 Overall, about a quarter of exploited species targeted by SSF and RF in coastal waters were  
41 vulnerable, making up nearly 50% of the total SSF catch and nearly 20% of the total recreational  
42 catch. In offshore waters, 100% of the RF and SSF catch was made up of vulnerable species. .  
43 Among the species caught as bycatch in both areas by SSF and RF, there was a total of 27  
44 vulnerable vertebrate species, which included birds, cetaceans, elasmobranchs and sea turtles.

45 The results also highlight the need to differentiate between different fishing methods or gears  
46 when studying the fishing impacts on vulnerable species. Our results indicate that although  
47 recreational and small-scale fisheries are often considered to have a relatively low ecological  
48 impact, a range of different fishing methods are affecting vulnerable species in coastal or  
49 offshore waters in the western Mediterranean Sea, be they targeted or taken unintentionally as  
50 bycatch.

51

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

54

## 55 **Introduction**

56 The magnitude of the ongoing extinction crisis has generated a huge effort aimed at evaluating  
57 and monitoring the risk of extinction faced by species worldwide. The trade-offs between  
58 economic, social and conservation objectives become severely problematic when the  
59 vulnerability of exploited species to fishing is high and the economic value of these species is  
60 also high (Norse *et al.*, 2012). Increasing global consumption of marine resources, together with  
61 environmental changes, has led to widespread loss and degradation of marine ecosystems, with  
62 potentially serious consequences for biodiversity and ecosystem services (Bianchi and Morri,  
63 2000; McCauley *et al.*, 2015; Webb and Mindel, 2015). Throughout the world, many exploited  
64 marine species are experiencing declines in population because of overfishing and other  
65 stressors, including climate change. Moreover, the systematic differences among different

66 species in their sensitivity to fishing is partly responsible for the increasing dominance of less  
67 vulnerable fish species in global catches, as the vulnerable ones become easily overexploited  
68 (Cheung *et al.*, 2007). Consequently, global, regional, national, and local lists of threatened  
69 species, including those listed in the international conventions for the protection of flora and  
70 fauna, have proliferated over the past decades (Burton, 2003) and these lists and conventions  
71 have undeniably become valuable tools for conservation (Rodrigues *et al.*, 2006; Miller *et al.*,  
72 2006; Dulvy *et al.*, 2006). Recently, the IUCN Red List has been proposed as a tool to  
73 complement or enhance existing indicators for sustainable use of marine resources, as  
74 described in the European Commission's Marine Strategy Framework Directive for monitoring,  
75 which applies an ecosystem approach to fisheries management (EC, 2014). Furthermore,  
76 quantitative indices, such as the intrinsic vulnerability index of marine fish (Cheung *et al.*, 2007),  
77 have been developed to address the specific vulnerability of fish to external pressures.

78 Recreational and small-scale (professional) fishing are important socioeconomic activities in  
79 the Mediterranean, taking place in coastal areas, as well as in offshore waters (reviewed by  
80 Lloret *et al.*, 2018). Recreational fishing (RF) in the Mediterranean, according to Font *et al.*  
81 (2012), comprises all non-commercial fishing that is carried out for leisure or sport, where the  
82 catch - the selling of which is illegal - is for one's own consumption (or for family and friends). It  
83 is particularly popular in the European Mediterranean, with the total number of recreational  
84 sea fishers estimated to be approximately 2.8 million (Hyder *et al.*, 2018), but also in non-  
85 European countries such as Tunisia (Ben Lamine *et al.*, 2018) and Turkey (Tunca *et al.*,  
86 2016).The Mediterranean has an extensive coastline, a huge population living in coastal areas  
87 (150 million people according to IUCN, 2019) and the importance of fishing as a leisure or

88 tourist activity is increasing (Font *et al.*, 2012). The expenditure by European recreational sea  
89 fishers in the Mediterranean has been estimated to be around €0.92 billion (Hyder *et al.*, 2018).  
90 In coastal waters (less than, approximately, 12 miles from the shore), recreational fishing  
91 methods are highly diverse, including boat fishing, shore fishing, spearfishing and shellfish  
92 gathering, sometimes carried out individually and sometimes in groups (for example in  
93 competitions and on chartered boats) (Font *et al.*, 2012). In offshore waters (more than,  
94 approximately, 12 miles from the shore), various gears are used by recreational boat fishers,  
95 such as rods with line and reel and trolley rigs, and they mainly target large pelagic predator  
96 fish species, which include sharks, although information is scarce (ADAP, 2017, Fowler *et al.*,  
97 2005).

98 Professional, small scale fishing (referred to as SSF throughout this paper) is defined,  
99 according to the European Parliament (2014), as “fishing carried out by fishing vessels of an  
100 overall length of less than 12 m and not using towed fishing gear”. SSF involves boats with  
101 smaller crews (1–3 fishers per vessel) and uses a wide variety of fishing techniques, including  
102 trammel net, gillnet, longline and pound nets, which are mostly passive gears targeting a wide  
103 array of seasonally changing benthic and pelagic coastal species (Lloret *et al.*, 2018). Offshore  
104 SSF mostly targets large pelagic predatory fish using, in most cases, pelagic longlines (Biton-  
105 Porsmoguer and Lloret, 2018). Although there are also other offshore fishing vessels using  
106 bottom longlines and gillnets to target benthic demersal fish, such as European hake  
107 (*Merluccius merluccius*) and blackspot seabream (*Pagellus bogaraveo*), these vessels are usually  
108 larger than 12 m length and therefore cannot be considered as SSF (Ungaro *et al.*, 2015). SSF is  
109 of great importance in terms of job opportunities and their contribution to the economy of

110 coastal communities in Europe: they have been estimated to generate about half of all direct  
111 employment within the EU fishing sector, representing approximately 83% of the fishing vessels  
112 and a quarter of the catch value (Guyader *et al.*, 2013; FAO, 2018). According to recent  
113 estimations (Hyder *et al.*, 2018), in a number of northern European countries, removals by  
114 marine recreational fisheries accounted for a significant proportion (up to more than 50%) of  
115 the total removals (both recreational *and* commercial) of species such as western Baltic cod  
116 (*Gadus morhua*) and European sea bass (*Dicentrarchus labrax*).

117 RF and SSF in European waters, and particularly in the Mediterranean, involve smaller  
118 catches, lower impact on habitats, lower annual fuel oil consumption, less bycatch and discards  
119 and less of the catch is reduced to fishmeal and oil than is the case with large-scale fisheries  
120 such as trawling and purse-seining (Lloret *et al.*, 2018; Tsagarakis *et al.*, 2014; Kelleher, 2005).  
121 Consequently, they are often considered to have a smaller ecological impact. However, from a  
122 biological standpoint, there are several features of these fisheries that may threaten the  
123 conservation status of certain species (Lloret *et al.*, 2018). Such species include benthic and  
124 pelagic long-lived and slow-growing species with low reproductive potential and a narrow  
125 geographic range (e.g. Lloret and Font, 2013; Luna-Pérez, 2010; Lloret *et al.*, 2016; Biton-  
126 Porsmoguer and Lloret, 2018). Furthermore, there is a widespread international agreement  
127 that bycatch in many fisheries raises ecological concerns that require the urgent attention by  
128 fisheries management (Zeller *et al.*, 2018). Although some studies have looked into the impact  
129 of specific small-scale and recreational fishing gears on particular vulnerable species in the  
130 Mediterranean (e.g. Morales-Nin *et al.*, 2010; Font and Lloret, 2014, Biton-Porsmoguer and  
131 Lloret, 2018), none of these studies have assessed the overall impact of small-scale and

132 recreational fisheries on vulnerable species in an integrated way, taking into account both  
133 coastal and offshore waters, as well as target species and bycatch species, and the different  
134 fishing gears employed.

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



153 to attain the favorable conservation status (defined in the Habitats Directive) for these species  
154 and the habitats they inhabit.

155

## 156 **Methods**

### 157 **Catch of target species**

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

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

167 Information was collected from a total of 40 studies comprising scientific articles (8) as well  
168 as grey literature (32) including unpublished reports and documents provided by researchers  
169 and managers of MPAs, where most of the research regarding RF in the Mediterranean has  
170 been carried out. These studies were carried out in a variety of ways encompassing a diverse  
171 range of sampling periods, duration and different recreational fishing types (Supplementary  
172 Table SB1). For the purpose of this study, fishing types are defined as: boat fishing (BF), shore  
173 fishing (SF) and spearfishing (SP). Although some of these studies did not always classify the

174 data according to fishing methods, and for certain areas there is a lack of information regarding  
175 particular fishing types, those we have reviewed represent the best source of available  
176 information so far. It must be pointed out, nevertheless, that there is very little information on  
177 RF outside spring and summer, during which the vast majority of samplings (90%, all areas  
178 combined) were carried out (Supplementary Table SB1). Therefore, our analysis is  
179 representative of the warmer season only, which is nevertheless the high season for RF in most  
180 of the areas (Font and Lloret, 2013, 2014). In addition to the revision of literature, the  
181 managers of each MPA and seven local scientists who specialize in coastal fisheries were  
182 contacted by email to obtain information on the catch of vulnerable species by recreational  
183 fishers through standardized questionnaires designed specifically to gather the same  
184 information from each area (i.e. the presence of vulnerable species in the catch of recreational  
185 fishers). Around 65% of the managers and scientists contacted provided the information  
186 required for further analysis. The rest were unable to provide information because their MPAs  
187 had only recently been created, which meant sufficient data on RF activity had not yet been  
188 collected.

189 The available information from SSF was provided by monitoring in three MPAs where  
190 information was available: Cap de Creus (Spain), Côte Bleue (France) and Cerbère-Banyuls  
191 (France). Studies in Cap de Creus MPA were conducted in 2008, 2009, 2010, 2011, 2013 and  
192 2015 via 572 onboard samplings, mostly carried out in spring and summer. The sampling  
193 scheme had two components. The first involved interviewing small-scale fishers and conducting  
194 on-board inspections. Fishers were interviewed and a sampling report was completed, which  
195 included the fishing gear used, location (fishing site), the date and time that the gear was set or

196 cast and when it was removed, and the quantity of fishing gear (number of hooks, length of  
197 nets, etc). The second, employing an increasingly common method for collecting fishery data,  
198 consisted of a self-sampling program by the fishers themselves enabling them to provide  
199 information from their own fishery. Overall, different boats from the various ports in the Cap de  
200 Creus area where small-scale fishers land their catches were sampled to gather information  
201 according to fishing type (trammel net, gillnet, longline and pound net). Meanwhile, data on  
202 species and catches from the Côte Bleue MPA were gathered during 261 small-scale fishing  
203 operations – involving trammel net, gillnet and longline – that were carried out in all seasons  
204 from 2012 to 2015. In this MPA, some species (mainly small-sized species such as labrids and  
205 serranids with little or no commercial value) were not taken into account because of  
206 insufficient data. Finally, the data on species and catches from the Cerbère-Banyuls MPA were  
207 gathered during 2015 (spring and summer), but only for trammel net fishing operations. The  
208 available information from these three MPAs was then collated with the aim of studying the  
209 effect of fishing type. Unfortunately, a wide range of sources were used to gather all the  
210 available information, which meant the data were heterogeneous in terms of fishing gears,  
211 years and seasons (i.e. the same data on all types of gears or years or seasons was not available  
212 for each area). Therefore, we proceeded to pool what data we had from all areas and only  
213 considered testing the effect of fishing type. Further details of the sampling methodology  
214 employed to monitor SSF in Cap de Creus, Côte Bleue and Cerbère-Banyuls MPAs are given in  
215 Lloret *et al.* (2015), Charbonnel *et al.* (2013, 2017) and Prats (2016), respectively.

216 Information relating to offshore catches was only available for the Spanish Mediterranean  
217 coast. Data on the catch of pelagic species by RF, gathered in 2017, was provided by the

218 Spanish General Secretary of Fisheries. The raw data gives the number of individuals caught;  
219 hence, the total weight of the catch by species was estimated by multiplying the number of  
220 individuals caught by the estimated weight of the individuals. We estimated an average weight  
221 of 15 kg for each specimen of swordfish, given that the Spanish authorities stated that  
222 individuals weighed less than 20kg and the minimum legal weight is 10 kg. For tuna species, we  
223 also estimated an average weight of 15 kg for each specimen, using information provided by  
224 the fishers. Additionally, in the catch there were some specimens of European hake; in this case  
225 we assumed an estimated average weight of 0.6 kg for each specimen, again using information  
226 provided by the fishers). With regard to the SSF catch of pelagic species, data were obtained for  
227 2017 from the landing statistics recorded by the Autonomous governments of Andalucía,  
228 Murcia, Valencia, Catalonia and the Balearic Islands.

229

### 230 **Vulnerability of target species**

231 From the catch made by SSF and RF in coastal waters and offshore, we first identified those  
232 exploited species that can be considered as “vulnerable to fishing” (Table 2). To do so, we first  
233 selected all the species in the catch that are included in the IUCN Red List - Mediterranean  
234 regional assessment ([www.iucnredlist.org](http://www.iucnredlist.org)) as *Threatened* (i.e. *Critically Endangered-CR*,  
235 *Endangered-EN* and *Vulnerable-VU*) and *Near Threatened-NT*. The IUCN Red List is recognized  
236 as one of the most reliable sources of information on the global conservation status of plants  
237 and animals (Rodrigues *et al.*, 2006) and classifies species at high risk of global extinction under  
238 different categories following well established criteria (IUCN, 2015).

239 Second, we selected those species included in the IUCN Red List as *Least Concern-LC* but with  
240 an index of vulnerability (IV) higher than 60 (i.e. high to very high vulnerability; Cheung *et al.*,  
241 2007). The IV index of a species defines the intrinsic vulnerability of marine fish to fishing,  
242 calculated using a fuzzy logic expert system, and is based on the life history traits and ecological  
243 characteristics of marine fish, such as maximum body length, age at first maturity, the von  
244 Bertalanffy growth parameter  $k$ , natural mortality, maximum age, geographical range, fecundity  
245 and the strength of aggregation behavior (Cheung *et al.* 2005). Generally, the most vulnerable  
246 fish are deemed to be species with larger body size, higher longevity, higher age at maturity,  
247 lower growth rates, a low reproductive potential and a narrow geographical range. These IV  
248 values were obtained from FishBase platform (Froese and Pauly, 2016;  
249 <http://www.fishbase.org/>) in the case of fish, and from the SealifeBase platform  
250 (<http://www.sealifebase.org/>) for organisms other than fish. Thirdly, we included in the  
251 selection of vulnerable exploited species three decapod species (*Homarus gammarus*, *Scyllarus*  
252 *arctus* and *Scyllarides latus*) which, despite being on the IUCN Red List as *Least Concern* or Data  
253 Deficient and having an IV index lower than 60, were nevertheless included in the Barcelona,  
254 Bern, and CITES conventions, and/or in the EU Habitats Directive.

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

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

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

266

### 267 **Vulnerability of the bycatch**

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

278

## 279 **Results**

280

281 **Coastal waters**

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

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

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

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

315

## 316 **Offshore waters**

317 In offshore waters, small-scale fishers fishing with pelagic longlines caught four species, *T.*  
318 *thynnus*, *Xiphias gladius*, *T. alalunga* and *Prionace glauca*, all of which, again, are vulnerable  
319 (Supplementary Table SB2, Figure 2). At the same time, recreational boat fishers caught three  
320 species, *Thunnus thynnus*, *T. alalunga* and *M. merluccius*, all of which are vulnerable  
321 (Supplementary Table SB2, Figure 2). In other words, 100% of the offshore SSF and RF catch  
322 comprises vulnerable species. In 2017, Spanish recreational boat fishers declared a catch of



323 0.87 tonnes of *T. thynnus*, 0.75 tonnes of *T. alalunga* and 0.002 tonnes of *M. merluccius*. Hence,  
324 *T. thynnus* and *T. alalunga* are by far the two main constituents of the total offshore  
325 recreational catch (99.8%). Also in 2017, Spanish offshore SSF operating with pelagic longlines,  
326 landed a total of 1,329 tonnes of swordfish (*X. gladius*), 207 tonnes of *T. alalunga*, 32 tonnes of  
327 *P. glauca* and 0.13 tonnes of *T. thynnus*. In this case, 84.8% of the offshore pelagic longline  
328 catch consisted of swordfish alone.

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

335 In the case of offshore fisheries, the mean IV index of the SSF catch was 62.58 while that of  
336 the recreational fishing catch was 62.23, both corresponding to levels considered as 'high'  
337 (Figure 3).

338

### 339 **Bycatch of vulnerable species**

340 Due to a lack of specific data on the methods used, the bycatch of vulnerable species could not,  
341 as we mentioned earlier, be analyzed separately for coastal and offshore waters. The combined  
342 bycatch in both areas by SSF and RF included a total of 27 vulnerable vertebrate species, which  
343 are listed in Supplementary Table SB3. Small-scale fishing methods led to the unintended

344 capture of 6 mammal species, 3 turtle species, 8 elasmobranchs, 1 osteichthyes and 6 different  
345 species of seabirds. Longlines (demersal, pelagic and drifting) were responsible for the highest  
346 number of vulnerable species in the bycatch (20 species), followed by driftnets (11), gillnets (8)  
347 and trammel nets (8). Meanwhile, RF unintentionally catch 8 vulnerable species: 3  
348 elasmobranchs, 1 osteichthyes and 3 seabirds. The vulnerable species appearing in the bycatch  
349 include 4 elasmobranchs (*Isurus oxyrinchus*, *Sphyrna zygaena*, *Lamna nasus* and *P. glauca*) and  
350 one bird (*Puffinus mauretanicus*) that are on the IUCN Red List as critically endangered species.  
351 There is also one mammal (*Physeter macrocephalus*) and three sea turtles (*Caretta caretta*,  
352 *Dermochelys coriacea* and *Checlonia mydas*) which are listed in Annex I of the CITES convention  
353 (Annex I lists the most endangered species recorded in CITES records, i.e., those under threat of  
354 extinction). In addition, the bycatch includes a number of other chondrichthyans, including  
355 *Cetorhinus maximus*, *S. zygaena*, *L. nasus* and *Alpias vulpinus* listed in Annex II of CITES (Annex II  
356 lists species that may not, as yet, be under imminent threat of extinction).

357

## 358 **Discussion**

359 This paper provides new information on the vulnerability of the catch and bycatch associated  
360 with recreational and small-scale fisheries operating in coastal and offshore waters in the  
361 western Mediterranean Sea. Although generally speaking these fisheries have a smaller  
362 ecological impact than large-scale ones (i.e. smaller catches, lower impact on habitats, lower  
363 annual fuel oil consumption, less bycatch and discards and less of the catch reduced to fishmeal  
364 and oil; Kelleher, 2005; Tsagarakis *et al.*, 2014; Lloret *et al.*, 2018), the results of this study show

365 that they may pose a threat to vulnerable species. In order to identify the vulnerable species  
366 among all the species caught, a framework is provided, based on the IUCN Red List,  
367 international conventions for the protection of flora and fauna, the Habitats Directive and the  
368 intrinsic vulnerability index of marine fish.

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

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

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

395 It must be noted, however, that it is not only the fishing method (small-scale, recreational,  
396 boat, shore, etc.) that may cause more or less important impacts on resources and vulnerable  
397 species, but also the fishing gear used within each method (e.g. trolling, bottom fishing, jigging,  
398 spinning, trammel net for cuttlefish, trammel net for red mullet, etc) all of which may have  
399 different impacts. Although we did not have the data classified by gear, it would be advisable in  
400 future monitoring programs to collect the information by fishing gear/method in order to  
401 identify which fishing types and methods have the greatest impact, in order to establish more  
402 gear-oriented restrictions and management actions.

403 In addition, this study has highlighted the fact that there were many vulnerable species of  
404 mammals, elasmobranches, turtles and birds caught as bycatch by small-scale and recreational  
405 fishing gears in coastal and offshore waters. These species are listed in the various annexes of  
406 the Habitats Directive and Birds Directive, which represent greater protection needs than the  
407 international conventions for the protection of biodiversity (i.e. Barcelona, Bern, Bonn, CITES),

408 the IUCN Red List and/or the EU Habitats Directive. SSF are responsible of the largest number of  
409 species in the bycatch, with trammel nets and driftnets being the fishing gears that  
410 unintentionally catch the greatest number of vulnerable species.

411 Elasmobranchs are a group of fish that appear in both the list of target and bycatch species  
412 caught by SSF and RF operating in coastal and offshore waters, which present an array of  
413 challenges for fisheries management and conservation (Fowler *et al.*, 2005, Gibson *et al.*, 2008).  
414 They are generally vulnerable to fishing because of peculiar characteristics of their life cycle  
415 (low fertility rate, slow growth and late maturity; Dulvy *et al.*, 2003; Gibson *et al.*, 2008). As a  
416 result, these species, which play a key role in maintaining the balance in marine ecosystems  
417 (Ferretti *et al.*, 2010), have a generally limited capacity to restore their population and  
418 consequently can be more easily endangered by fishing (Fowler *et al.*, 2005, Gibson *et al.*,  
419 2008). For example, recent studies highlight the current population decline – or even, in some  
420 cases, local extinction – of several elasmobranchs in waters around the Balearic Islands, where  
421 they had previously been quite common (Farriols *et al.*, 2017; Mayol *et al.*, 2000; Grau *et al.*,  
422 2015; Ligas *et al.*, 2013; Ferretti *et al.*, 2008). Similar rarefactions have also been documented in  
423 other Mediterranean areas (Maynou *et al.*, 2011; Ligas *et al.*, 2013; Coll *et al.*, 2014) and in  
424 other seas and oceans (Ferretti *et al.*, 2008).

425 Mediterranean fisheries are expected to continue to exert a significant impact on vulnerable  
426 target and bycatch species in the foreseeable future, but the scale of the impact will be  
427 different for each sector. For SSF, the impact will remain high but possibly decreasing in many  
428 coastal areas if the recent decline observed in SSF continues in the coming years (Lloret *et al.*,  
429 2018). In contrast, it appears that the impact on vulnerable species by recreational fisheries will

430 continue to rise with increased activity from this sector reported not only in coastal waters  
431 (Lloret *et al.*, 2018), but also in offshore waters, where considerable growth in the number of  
432 sport fishers has been observed over the past few years off the Italian, Spanish and French  
433 coasts. For example, the number of Spanish recreational boats with special authorization to fish  
434 large pelagic fish species in the Mediterranean increased between 2015 and 2017, from 661 to  
435 917. The data analyzed in this paper suggests that, in offshore waters, the current impact of SSF  
436 is much higher than that of RF (with the SSF catch of pelagic species being several times higher  
437 in comparison). Despite this, the impact of each sector in coastal waters has been found to be  
438 similar in some areas such as, for example, in the MPA Cap de Creus (Lloret *et al.*, 2008b).

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

451 and the number of years in operation, on the catch of vulnerable species in order to better  
452 understand the effects of these fisheries under different circumstances.

453 The findings of this study should help to provide basic guidelines for both managers and  
454 policy makers in their work to develop specific management measures that will ensure the  
455 protection of vulnerable species caught by small-scale and recreational fisheries in the western  
456 Mediterranean Sea, while safeguarding small-scale fisheries in accordance with the FAO  
457 guidelines on SSFs (FAO, 2015) and ensuring the sustainability of recreational activities, which  
458 are becoming increasingly important in the economies of a number of Mediterranean countries  
459 (Lloret *et al.*, 2018). These measures, based on the precautionary principle, could include  
460 reducing the fishing pressure on certain vulnerable species (e.g. by regulating fishing gears and  
461 baits) or, in some cases, prohibiting their capture, at least in specific areas, such as marine  
462 protected areas (MPAs), and/or in particular seasons of the year. A number of studies have  
463 demonstrated the valuable role played by Mediterranean MPAs, particularly under certain  
464 circumstances (e.g. sound protection of habitats and species, strong enforcement of laws,  
465 optimal size, etc) in protecting and rebuilding the populations of vulnerable species (Harmelin-  
466 Vivien *et al.*, 2015; Giakoumi *et al.*, 2017; Di Franco *et al.*, 2018), and that seasonal closures  
467 during the reproductive season are effective in the protection of spawning aggregations of  
468 vulnerable species (Sadovy de Mitcheson *et al.*, 2013). Furthermore, minimum landing sizes  
469 should be implemented for all vulnerable species, whereas maximum landing sizes should be  
470 also implemented for sex-changing species such as *E. marginatus*, *Pagrus pagrus* and *L. viridis* in  
471 order to preserve their reproductive potential (Lloret *et al.*, 2012).. In light of recent evidence of  
472 strong competition between illegal and legal fishing (by both professional and recreational

473 fishers) in the Mediterranean Sea (Ben Lamine *et al.*, 2018), it is also paramount to combine  
474 protective measures with an effective enforcement (Sadovy de Mitcheson *et al.*, 2013), and to  
475 promote greater public awareness, which can lead to support for legislation and action at the  
476 consumer end of the supply chain by empowering customers to make better seafood choices,  
477 for example, by avoiding the consumption or the catch of vulnerable species. In this sense,  
478 public awareness will contribute to the so-called “rewilding” initiatives, which are emerging as a  
479 promising restoration strategy in a human-dominated world to promote self-sustaining  
480 ecosystems and enhance the conservation status of biodiversity (Torres *et al.*, 2018). Finally,  
481 technical solutions aimed at avoiding/minimizing bycatch are needed to avoid the catch of  
482 vulnerable elasmobranchs, sea birds, mammals and turtles, including the prohibition of fishing  
483 in particular areas and seasons in which these animals appear in greater abundance.

484 These protective measures are not only necessary to safeguard vulnerable species from  
485 overfishing or extinction, but are also important in ensuring the favorable conservation status  
486 (FCS) of Special Areas of Conservation (SACs), which are strictly protected sites designated  
487 under the EU Habitats Directive in European waters. The vulnerable species affected by small-  
488 scale and recreational fisheries in coastal waters of the Mediterranean inhabit different  
489 habitats included in this Directive, such as Posidonia meadows and coralligenous assemblages.  
490 The protection of vulnerable species that are typical in these habitats is necessary to attain the  
491 desired FCS in European waters.

492 In some cases, the EU, national and/or regional managers have already begun to implement  
493 rules to protect vulnerable species from overfishing, enabling certain populations to recover –  
494 although such measures remain somewhat limited, particularly in coastal waters. There is, for



495 example, in French Mediterranean coastal waters (including Corsica), a ban on recreational  
496 hook and line fishing and spear fishing for brown meagre (*S. umbra*), and a ban on professional  
497 and recreational hook and line fishing for groupers (*Epinephelus* spp., *Mycteroperca rubra* and  
498 *Polyprion americanus*), until at least 2023. Also, recreational fishers are not allowed to catch  
499 the vulnerable decapods *Palinurus elephas* and *Scyllarides latus* in Spain, nor *S. latus* in France  
500 and Italy (furthermore, professional fishers in France are not allowed to catch *S. latus*) In Italy, it  
501 is forbidden to fish mature female of *P. elephas* and *Hommarus gammarus* by any recreational  
502 fishing method, and any crustacean with spearfishing. Although there is very little published  
503 information on illegal fisheries, there are, nevertheless, indications that poaching does occur;  
504 for example, in the MPA of Calanques (France), poachers are reported to be targeting the  
505 larger, older females of two protected species, the dusky grouper (*E. marginatus*) and the  
506 brown meagre (*Sciaena umbra*) (Astruch *et al.*, 2018).

507 In offshore waters, some legislative measures to protect vulnerable species are also in place.  
508 France for example has forbidden the on-board presence, landings and sale of swordfish by  
509 recreational fisheries (although catch and release is allowed in particular months). Also in  
510 France, the recreational fishing of *T. thynnus* requires a special authorization. Restrictive  
511 measures in France affect other pelagic vulnerable species, such as *Raja undulata*, fishing of  
512 which is forbidden. In Spain, recreational fishers cannot fish for pelagic sharks, such as *P.*  
513 *glauca*, although they have no obligation to report bycatch. As with recreational fisheries, the  
514 commercial fisheries of large pelagic fish are often regulated by specific national regulations.  
515 For example, in Spain, professional fishers are obliged to request specific authorization, and a  
516 catch and release declaration must be completed. Furthermore, protective measures have been

517 established for several large pelagic vulnerable species that can be caught by recreational  
518 fishing, including *T. alalunga*, *T. thynnus*, *T. obesus*, *Makaira spp.*, *Tetrapturus spp.*, *Istiophorus*  
519 *albicans* and *X. gladius*. Other regulations have also been established by the European  
520 Commission (EC), banning the catch, trade or landing of several shark species, including *C.*  
521 *maximus*, *Z. zygaena*, *L. nasus* and *A. vulpinus*, by recreational and professional fisheries.  
522 Furthermore, the EU, in the case of recreational fishing, authorizes the catch of only one  
523 individual swordfish per day and boat, with a minimum fork length of 100 cm or a minimum  
524 weight of 10.2 kg. Furthermore, the EU has banned the fishing of certain shark and  
525 elasmobranch species for all professional and recreational fishing fleets, while fishing for *T.*  
526 *thynnus* and *X. gladius* in the Mediterranean by small-scale fisheries is subject to closed seasons  
527 and quotas established by ICCAT in all contracting countries. Finally, some of the large  
528 vulnerable pelagic species such as Bluefin tuna and swordfish are subject to recovery plans that  
529 establish specific measures for small-scale and recreational fisheries throughout the  
530 Mediterranean or in certain specific areas. Finally, it must be pointed out that although this  
531 analysis provides a general picture of the potential impact of RF and SSF on vulnerable species,  
532 there are still some uncertainties regarding the results. For example, the fact that marine RF in  
533 Europe are usually subject to different national, regional and MPA legislation results in different  
534 restrictions on fishing methods and techniques (e.g. spear fishing is not allowed in a number of  
535 MPAs), different total catch limits for certain species, and different species authorized for  
536 catch; this, in turn, produces uncertainty with respect to the harvested biomass. Furthermore,  
537 the fact that the RF surveys are mostly carried out during the summer season may lead to an

538 underestimation of the impact of recreational fisheries on species that tend to be caught during  
539 the winter season, such as *D. labrax*.

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

549

#### 550 **Supplementary data**

551 Supplementary material is available at the ICESJMS online version of the manuscript

552

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561

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734 **FIGURE CAPTIONS**

735

736 Figure 1: Map of the study area showing the coastal areas and marine protected areas  
737 considered. The sites marked with the symbol \* are designated (wholly or partially) as Special  
738 Areas of Conservation (SAC). The code numbers are: 1-Bonifacio\*; 2-Bergeggi (adjacent area),  
739 3-Cap Roux (adjacent area), 4-French Riviera\*, 5-Port-Cros\*, 6-Porquerolles\*, 7-Archipel des  
740 Embiez-Six Fours\*, 8-Archipel de Riou, 9-Côte Bleue\*, 10-Cap d'Agde\*, 11-Côte sableuse  
741 catalane, 12-Posidonies Côte des Albères \*, 13-Cerbère-Banyuls\*, 14-Cap de Creus\*, 15-Medes  
742 Islands\*, 16-Coast of Catalonia, 17-Serra Gelada\*, 18-Tabarca\*

743

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

752

753 Figure 3: Weighted mean intrinsic vulnerability index (IV) by fishing type operating in coastal  
754 and offshore waters. Recreational fisheries (BF: boat fishing; SF: shore fishing; SP: spearfishing;

755 OBF: offshore boat fishing) and small-scale fisheries (TR: trammel net; GN: gillnet; LL: longline;

756 PN: pound net; OLL: offshore long line)

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