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► **To cite this version:**

J Lloret, S Biton-Porsmoguer, A Carreño, A Di Franco, R Sahyoun, et al.. Recreational and small-scale fisheries may pose a threat to vulnerable species in coastal and offshore waters of the western Mediterranean. *ICES Journal of Marine Science*, 2020, 77 (6), pp.2255-2264. 10.1093/icesjms/fsz071 . hal-03034088

HAL Id: hal-03034088

<https://hal.science/hal-03034088v1>

Submitted on 1 Dec 2020

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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

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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) 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

553 **Acknowledgements**

554 The authors would like to thank all the scientists and administrative personnel, including MPA
555 managers and those in the fisheries administrations of Spain, France and Italy, who generously
556 collaborated in this study by providing data and other types of information. This study was
557 carried out within the framework of the EU Research Project SAFENET project (“Sustainable
558 Fisheries in EU Mediterranean Waters through Network of MPAs.”, Call for proposals MARE

559 /2014/41, Grant Agreement n. 721708). S. Biton-Porsmoguer benefited from a postdoctoral
560 fellowship (Reference ROMP–2017–200053791).

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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