

1 *Communication*

2 **New evidence of marine fauna tropicalization off the** 3 **southwestern Iberian Peninsula**

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15 **Abstract:** Climate change and the overall increase of seawater temperature is causing a poleward
16 shift in species distribution, which includes a phenomenon described as tropicalization of temperate
17 regions. This work aims at reporting the first records of four species off the southwestern Iberian
18 Peninsula, namely oceanic puffer *Lagocephalus lagocephalus* Linnaeus, 1758, Madeira rockfish
19 *Scorpaena maderensis* Valenciennes, 1833, ornate wrasse *Thalassoma pavo* Linnaeus, 1758, and bearded
20 fireworm *Hermodice carunculata* Pallas, 1766. These last three species, along with other occurrences of
21 aquatic fauna and flora along the Portuguese coast, reveal an ongoing process of poleward expansion
22 of several species for which a comprehensive survey along the entire Iberian Peninsula is urgent. The
23 putative origins of these subtropical and tropical species off continental Portugal are discussed, as
24 well as the urgent need of public awareness due to potential health risks resulting from the toxicity
25 of two of the four species reported in this paper.

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27 **Keywords:** climate change, tropicalization, species distribution, range expansion, North Atlantic

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30 **1. Introduction**

31 The effects of climate change are becoming evident across oceans, through changes on sea level,
32 ocean primary productivity, ocean acidification, water temperature, and shifts on species distribution
33 ranges [1]. In some temperate regions, the increase in seawater temperature is causing a poleward
34 movement of species, a phenomenon called tropicalization of temperate regions [2]. The global trend
35 is that this tropicalization phenomenon is occurring in several marine ecosystems [3]. Along the west
36 and east coasts of Australia, dense kelp forests are disappearing, with records of 100-km range
37 contractions in the west coast followed by the increase in subtropical and tropical herbivorous fish
38 that suppresses kelp recovery [4-6]. Other important habitat-forming species, as coral reefs, have been
39 expanding their poleward distribution along the Japanese coast at a rate of up to 14 km year⁻¹ [7].
40 Simultaneously, tropical fish species are settling in these regions and being able to withstand the
41 winter colder waters off Japan [8]. In the northern region of the Gulf of Mexico, an increasing number
42 of diverse southern tropical species (e.g., fish, manatees, turtles, warm-water corals, black
43 mangroves) are reshaping the characteristic seagrass meadows of the region [9]. Similar cases were
44 observed in the northern Mediterranean Sea since the early 1990's, where several southern warmer
45 water fish species have been recorded [2,10,11].

46 Along the southwestern and western coasts of the Iberian Peninsula (Europe), the distribution
47 range of several algae species shifted northwards on the order of hundreds and thousands of

48 kilometres [12,13]. There are also examples of new species being reported off southern Portugal, as
49 the brown mussel *Perna perna* Linnaeus, 1785 [14] and the parrotfish *Sparisoma cretense* Linnaeus, 1758
50 [15], which suggests that a wide array of species are shifting their northern distribution limit from
51 northern Africa to the Atlantic coasts of the Iberian Peninsula.

52 In this context, this work aims at reporting four new accounts of subtropical/tropical faunal
53 species observed for the first time in the south coast of Portugal and in the Guadiana estuary (SE-
54 Portugal/SW-Spain). These new records for the SW-Iberian Peninsula include three Teleostei, the
55 Madeira rockfish *Scorpaena maderensis* Valenciennes, 1833, the ornate wrasse *Thalassoma pavo*
56 Linnaeus, 1758, and the oceanic puffer *Lagocephalus lagocephalus* Linnaeus, 1758, as well as a
57 Polychaeta, the bearded fireworm *Hermodice carunculata* Pallas, 1766.

58 2. Materials and Methods

59 2.1. Study area

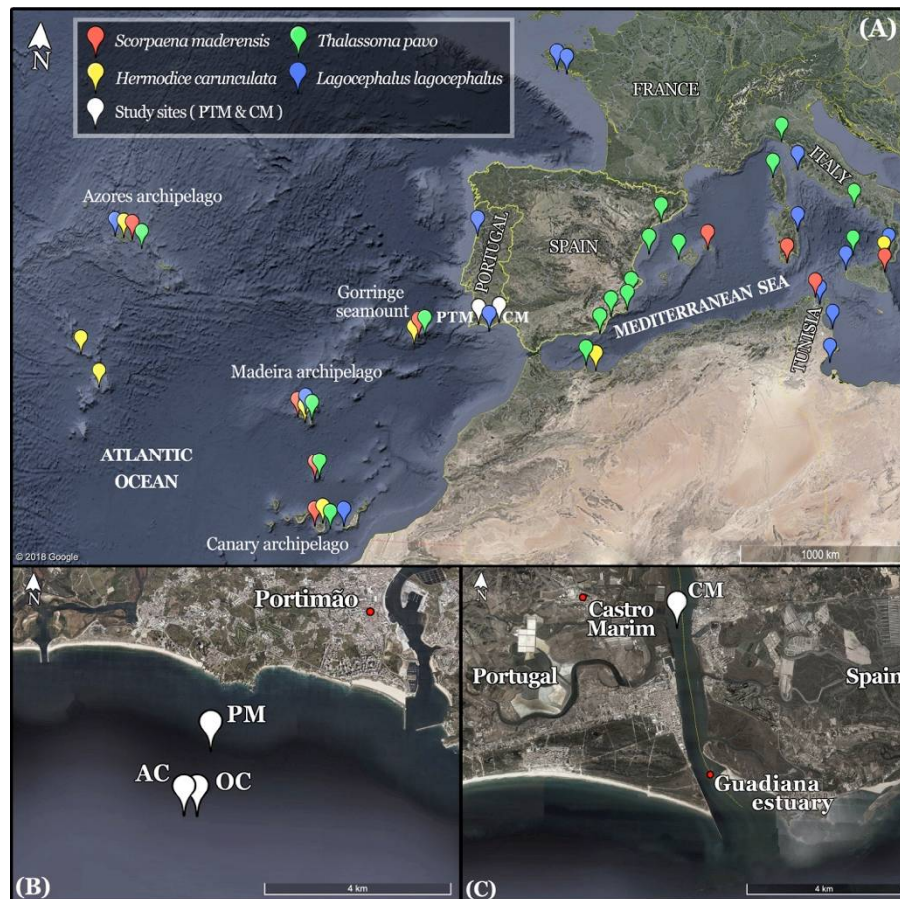
60 Three out of the four new records of marine fauna reported in this work were registered off
61 Portimão (SW-Portugal) (Figure 1A), at one natural reef and two artificial reefs. The natural reef is
62 known as “Pedra do Mariano” (37° 06.143' N, 8° 34.610' W) and the reef wall lays between 14 and 17
63 meters deep, mostly surrounded by rocky bottoms and scattered sandy areas (Figure 1B). The
64 artificial reefs are two sunken ships (Figure 1B), the “Oliveira e Carmo” corvette (37° 05.501' N 8°
65 34.964' W) and the “Almeida Carvalho” hydrographic ship (37° 05.391' N, 8° 34.960' W), which were
66 intentionally sunken to form the Ocean Revival underwater park (www.oceanrevival.org). These
67 ships lay at a depth of 30 meters over sandy bottoms and elevate to a minimum depth between 14
68 and 18 meters. A fourth species was registered in the in the lower Guadiana estuary (SE-Portugal/SW-
69 Spain) off Castro Marim (37° 12.717' N, 7° 24.867' W) (Figure 1C).

71 2.2. Data collection

72 In the region off Portimão, data was collected as part of recreational SCUBA diving trips on the
73 three sites, with species being photographed with a Canon G16 digital camera (12 megapixel
74 resolution). The depth at which species were photographed was annotated, and whenever possible
75 also their size and sex. Size was estimated whenever possible by including an object in the
76 photography to be used as scale, while sex assignment was done based on sexual dimorphism
77 characteristics if the species displays such trait.

78 In the Guadiana estuary, a local fisherman collected two specimens with a longline gear
79 deployed overnight, but only one specimens was delivered to us for identification. In the laboratory,
80 this specimen was identified, sexed, the total fresh weight (± 1 g) was determined, several
81 morphometric and meristic characteristics were measured and counted, and the stomach content
82 analyzed.

83 The identification of species was based on the photographs taken and on the collected specimen
84 and following the identification books of Saldanha [16] and Louisy [17].



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86 **Figure 1.** (A) The location of the two main study sites off Portimão (PTM) and in the lower
 87 Guadiana estuary off Castro Marim (CM) (SE-Portugal/SW-Spain) is shown in the context of the
 88 Iberian Peninsula and northern African coast. The location of the Gorringe seamount and of the
 89 three Macaronesian archipelagos is also signled. The markers on the Macaronesian islands only
 90 reflects the presence of each species at each archipelago and not their precise distribution in each
 91 island. Species distribution was compiled based on several scientific publications. (B) Location of
 92 the study sites off Portimão (PM – Pedro do Mariano; OC – Oliveira e Carmo corvette; AC –
 93 Almeida Carvalho hydrographic ship) and (C) in the lower Guadiana estuary off Castro Marim
 94 (CM). Maps retrieved from Google Earth.

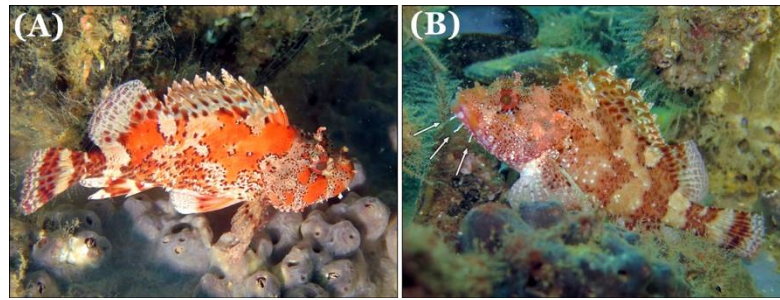
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96 3. Results

97 During the non-systematic diving surveys done off Portimão, three species were identified as
 98 new additions to the southwestern Iberian Peninsula's fauna. These species were the Madeira
 99 rockfish *Scorpaena maderensis* Valenciennes, 1833, the ornate wrasse *Thalassoma pavo* Linnaeus, 1758,
 100 and the bearded fireworm *Hermodice carunculata* Pallas, 1766, which are characteristic of subtropical
 101 and tropical regions.

102 The first Madeira rockfish specimen record occurred on July 29, 2016, in the "Oliveira e Carmo"
 103 corvette at a depth of 24 meters (Figure 2A). A second individual was observed in the same location
 104 on October 3, 2016, at a depth of 20 meters (Figure 2B).

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Figure 2. Photograph of Madeira rockfish *Scorpaena maderensis* (Valenciennes, 1833) on July 29th, 2016 (A) and on October 3, 2016 (B), both in the “Oliveira e Carmo” corvette. Arrows indicate the distinctive long white tentacles in the lower mandible (B).

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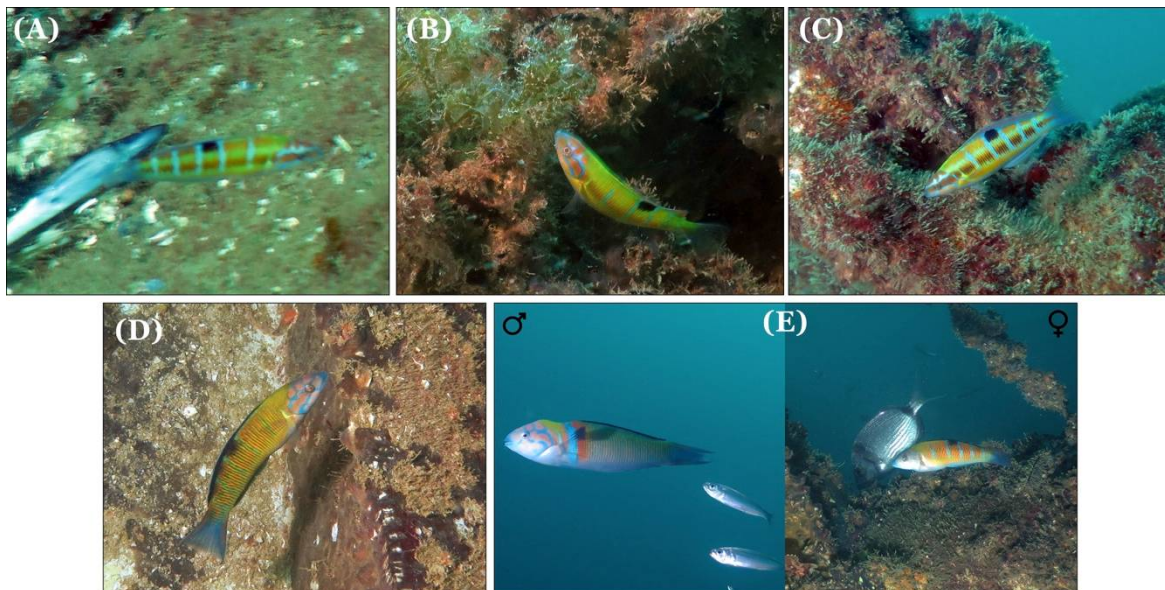
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The first observed ornate wrasse was a female, and was observed on May 8th, 2017, in “Almeida Carvalho” hydrographic ship at a depth of 17 meters (Figure 3A). A second specimen was observed in “Oliveira e Carmo” on May 15, 2017 (no photograph taken). A third specimen was observed in “Almeida Carvalho” on May 31, 2017, at a depth of 16 meters (Figure 3B). This individual’s coloration pattern suggests that it was going through the process of changing sex, from female to male. A fourth ornate wrasse was a female, observed in the same location on September 19, 2018, at a depth of 16 meters (Figure 3C). A fifth individual was observed in “Oliveira e Carmo” on September 22, 2018, at a depth of 20 meters (Figure 3D). This individual was in an advance transitional phase from female to male. On October 3, 2018, two other individuals (male and female) were identified in “Oliveira e Carmo” at 17-20 meters deep (Figure 3E).



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Figure 3. Photograph of ornate wrasse *Thalassoma pavo* (Linnaeus, 1758) on May 8, 2017 (A), May 31st, 2017 (B) and September 19, 2018 (C), all in the “Almeida Carvalho” hydrographic ship. A specimen observed on September 22, 2018 in the “Oliveira e Carmo” corvette (D) and on October 3, 2018, a male (left) and a female (right) observed in the “Oliveira e Carmo” corvette (E).

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The first and only record of a bearded fireworm occurred on September 7, 2018, in “Pedra do Mariano” natural reef at 16 meters deep. The total length of this specimen was ca. 33 cm (Figure 4).



129

130 **Figure 4.** Photograph of bearded fireworm *Hermodice carunculata* (Pallas, 1766) identified on
 131 September 7, 2018, at the “Pedra do Mariano” natural reef, with an approximate total length of
 132 33 cm.

133

134 In the Guadiana estuary, two specimens of oceanic puffer *Lagocephalus lagocephalus*
 135 Linnaeus, 1758 were collected by local fishermen, the first on May 23, 2017, and the second on October
 136 17, 2017. However, only the later specimen was delivered to us for analysis. This specimen was a
 137 male, with a total length of 37.2 cm and the total fresh weight was 453 g (Figure 5). All the
 138 morphometric and meristic characteristics are described in Table 1. The stomach content was empty.



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140 **Figure 5.** Photograph of a male oceanic puffer *Lagocephalus lagocephalus* (Linnaeus, 1758) specimen
 141 collected on October 17, 2017, in the lower Guadiana estuary off Castro Marim.

142

143 **Table 1.** Morphometric and meristic characteristics, as well as the total fresh weight, of the male
 144 oceanic puffer *Lagocephalus lagocephalus* (Linnaeus, 1758) specimen collected in the lower Guadiana
 145 estuary (SW-Europe) off Castro Marim (37°12'43" N, 7°24'52" W) on October 17, 2017.

Morphometric characteristics		Meristic characteristics	
Total length	37.2 cm	Anal fin	13
Fork length	34.5 cm	Caudal fin	II + 11 + II
Standard length	30.6 cm	Dorsal fin	16
Body depth	7.3 cm	Pectoral fin	16
Head length	8.3 cm		
Snout-eye length	3.5 cm	Total fresh weight	
Eye diameter	1.7 cm	Weight	453 g

146 4. Discussion

147 This work provides the first account of four new faunal species present off the Algarve (SW-
148 Iberian Peninsula, Europe). Of these, Madeira rockfish, ornate wrasse, and bearded fireworm, are
149 typical from the subtropical Macaronesia archipelagos [18-20] (Figure 1A) which might illustrate the
150 influence of rising seawater temperature on the poleward expansion of subtropical or tropical species,
151 i.e. tropicalization.

152 The Algarve coast is located in the south European Atlantic shelf ecoregion which borders three
153 other ecoregions: the Macaronesia archipelagos, the North-western African coast, and the
154 Mediterranean Sea [21]. The Algarve's location, i.e. at the intersection of three other ecoregions,
155 increases the possibility for the appearance of species that are typical from other ecoregions.

156 The Madeira rockfish is a common benthic species in all the Macaronesian archipelagos and
157 along the coasts of Morocco, Mauritania, and Senegal [22]. It is also present in the Mediterranean Sea,
158 from Greek waters [23], to the central Mediterranean [24,25], and eastwards in the Balearic Islands
159 [26]. The colonization of the Balearic Islands by the Madeira rockfish probably happened in the
160 beginning of the 1990's as a result of a northward expansion due to increasing water temperatures in
161 the southern Mediterranean [26]. However, misidentifications might have hindered the report of this
162 species earlier, as it occurred with *Scorpaena porcus* Linnaeus, 1758 in the Mediterranean Sea [24], a
163 species that is also present off southern Portugal along with the more common *Scorpaena notata*
164 Rafinesque, 1810 [27].

165 In the case of the ornate wrasse, another parallelism should be made with what is happening in
166 the Mediterranean Sea. The species was always abundant in the eastern basin [28] but until 1988, its
167 presence in the NW Mediterranean was sporadic, while during the early 1990's its density more than
168 doubled and juveniles were accounted for in subsequent years [10,28]. By 1997, a self-sustained
169 population with juveniles and adult males and females with mating behaviours existed in the
170 Ligurian Sea [29]. As other Labridae, the ornate wrasse is a protogynous hermaphrodite, which may
171 explain the occurrence of mostly females in our first three occurrences for the SW-Iberian Peninsula.
172 These hermaphroditic females can, given the right conditions, become successful territorial males at
173 a later phase of their life cycles, has shown for other *Thalassoma* species [30]. So, we propose that the
174 occurrence of transition-phase individuals and terminal-phase males during late 2018 (Figure 3D, 3E)
175 may indicate that the ornate wrasse is becoming established off the SW-Iberian Peninsula.

176 Regarding the bearded fireworm, this species is widely distributed in the Atlantic Ocean from
177 the Caribbean to the Macaronesian islands, the Mediterranean and Red Seas [20]. It is a voracious
178 and generalist omnivorous species, preying mainly on anemones, gorgonians, and milleporid
179 hydrocorals [31,32]. However, the venomous stings of bearded fireworm may raise a public health
180 concern if this species becomes abundant in the Algarve coast. The calcareous chaetae present
181 alongside the body deliver numerous toxins that cause intense pain, inflammation, and edema when
182 in contact with human skin, alongside with neurotoxins that can cause localized paresthesia and
183 numbness [33]. So, precautionary measures should be implemented to prevent people of touching
184 this species if it becomes widespread, especially in highly touristic regions as the Algarve.

185 The area of origin of these three new taxa is difficult to pinpoint, but the Macaronesian area
186 emerges as the likely origin. The Madeira and Canary Islands are located ca. 800 and 950 kilometres
187 SW of the Algarve, respectively, and the Azores Islands ca. 1450 kilometers westwards of the Cape
188 Saint Vincent (Figure 1A). Furthermore, the location of the Gorringe seamount at ca. 270 km WSW
189 from Cape Saint Vincent may function as a stepping-stone to facilitate the arrival of Macaronesian
190 species, as suggested for the damselfish *Abudefduf luridus* Cuvier, 1830 [34]. Indeed, all these three
191 species are present in the Gorringe seamount (Figure 1A), the Madeira rockfish was first recorded in
192 2006 [35], the ornate wrasse in 1998 [34], and the bearded fireworm in 2005 [36]. Apart from the
193 swimming capabilities of the fish species, these species display reproductive strategies that enable
194 them to disperse given the right oceanographic conditions, specifically if able to use branches of the
195 Azores Current which extends into the Gulf of Cadiz [37,38].

196

197 Although, the reproductive biology of the Madeira rockfish remains unknown, it is possible to
198 make comparisons with similar rockfish species, namely with *S. notata*, a common species along the
199 Algarve coast [27]. The females of this rockfish species deposit between 6000 to 33000 eggs into a
200 gelatinous matrix that provides mechanical protection while also acting as a floatation mechanism
201 [39,40], which thus increases their dispersal potential. In the case of the ornate wrasse, spawning is
202 pelagic and the larval phase lasts between 38 and 49 days, which is considered to be long in
203 comparison to other Labridae [41]. The reproductive biology of the bearded fireworm is still poorly
204 known. Nevertheless, the genus *Hermodice* is presumed to be able to reproduce both asexually and
205 sexually, through the release of planktonic gametes [42]. The lack of knowledge about the
206 reproduction of *H. carunculata* is also recognized, however it is likely that the species has a long-lived
207 planktotrophic larval phase which increases its potential to colonize new habitats [43].

208 The case of the oceanic puffer should be approached more carefully because the presence of
209 oceanic puffers away from tropical and subtropical regions is often reported [44-52], including in
210 estuarine ecosystems [49,53]. However, the report of oceanic puffers in the Guadiana came as a
211 surprise for local fishers. Still, this new account cannot be linked with climate change since oceanic
212 puffer was reported further north off Great Britain in the late 1940's [44,45] and 1960's [46], and in
213 the North Sea in the 1970's [54], i.e., during a period when climate change impact was negligible [55].
214 In the Mediterranean Sea, and as far as we are aware, the first record dates to 1878 [52]. So, the
215 increased frequency of reports in the Mediterranean Sea and in the northeastern Atlantic may simply
216 reflect the increased research effort of current times [47,48,50-52,56-58] However, all these facts do
217 not imply that climate change is not inducing, or will not induce, a poleward range expansion of
218 oceanic puffer populations. In the case of the Guadiana estuary, both climate change and the
219 disruption of natural river flow caused by the Alqueva dam might have contributed to the presence
220 of oceanic puffer specimens in the estuary in tandem with the proximity of the Algarve to subtropical
221 regions. Thus, and overall, oceanic puffer is not a good example to illustrate the impact of climate
222 change on aquatic species redistribution. At least for now. Similarly to the bearded fireworm, the
223 toxicity of the ocean puffer might pose a public health risk [52], which discourages its consumption
224 [57,59]. Therefore, scientists must continue their efforts to document the aquatic fish fauna, while
225 public health authorities should act promptly if the abundance of oceanic puffer increases in the
226 future.

227 Other faunal species with subtropical or tropical origins were already identified off the Algarve,
228 as the parrotfish *Sparisoma cretense* Linnaeus, 1758 in the Ria Formosa lagoon [15], the hermit crab
229 *Calcinus tubularis* Linnaeus, 1767 in shallow rocky reefs [60], or the brown mussel *Perna perna*
230 Linnaeus, 1758 in rocky intertidal shores [14]. However, such examples are not restricted to animals.
231 Regarding algae, there are examples of species expanding their distribution range and of others
232 whose distribution range is retracting. Along the portuguese coast, eight warm-water species showed
233 a poleward expansion of between 59 km (*Codium adhaerens* C. Agard) and 593 km (*Sargassum*
234 *flavifolium* Kützting). On the other hand, six cold-water species exhibited a poleward retraction of their
235 distribution between 62 km (*Dumontia contorta* (S.G.Gmelin) Ruprecht) and 358 km (*Palmaria palmata*
236 (Linnaeus) F.Weber & D.Mohr) [12]. The case of the bladder wrack brown algae *Fucus vesiculosus*
237 Linnaeus is particularly remarkable, being nowadays almost restricted to the NW coast of the Iberian
238 Peninsula, having its southern border of distribution in the Tejo estuary, while in 1986 it was still
239 present in the Moroccan coasts, representing a 1,250 km poleward shift of its distribution [13].

240 Finally, the collaboration of scientists with local fishers and the general public must be
241 encouraged to anticipate the detection of new species, as it already occurred for the oceanic puffer
242 (this study), weakfish *Cynoscion regalis* Bloch and Schneider, 1801, and the Atlantic blue crab
243 *Callinectes sapidus* Rathbun, 1896 [61-63]. These experiences clearly highlight the importance of
244 citizen-science initiatives.

245 5. Conclusions

246 The presence of the Madeira rockfish, ornate wrasse, and bearded fireworm off the SW-Iberian
247 Peninsula, and possibly the presence of the oceanic puffer in the Guadiana estuary, may represent

248 examples of poleward distribution range expansion of subtropical/tropical species. This hypothesis
 249 has support on multiple evidence from other species as described in this paper. We advocate for the
 250 implementation of systematic surveys along the Atlantic coast of the Iberian Peninsula,
 251 concomitantly with genetic analyses, to find support for the tropicalization hypothesis. We also
 252 propose that these new fish species should be monitored and included in local fisheries management
 253 plans if their abundance increases.

254

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270

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