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Communication

New evidence of marine fauna tropicalization off the southwestern Iberian Peninsula

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

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

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1. Introduction

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

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

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

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

2. Materials and Methods

2.1. Study area

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

2.2. Data collection

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

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

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

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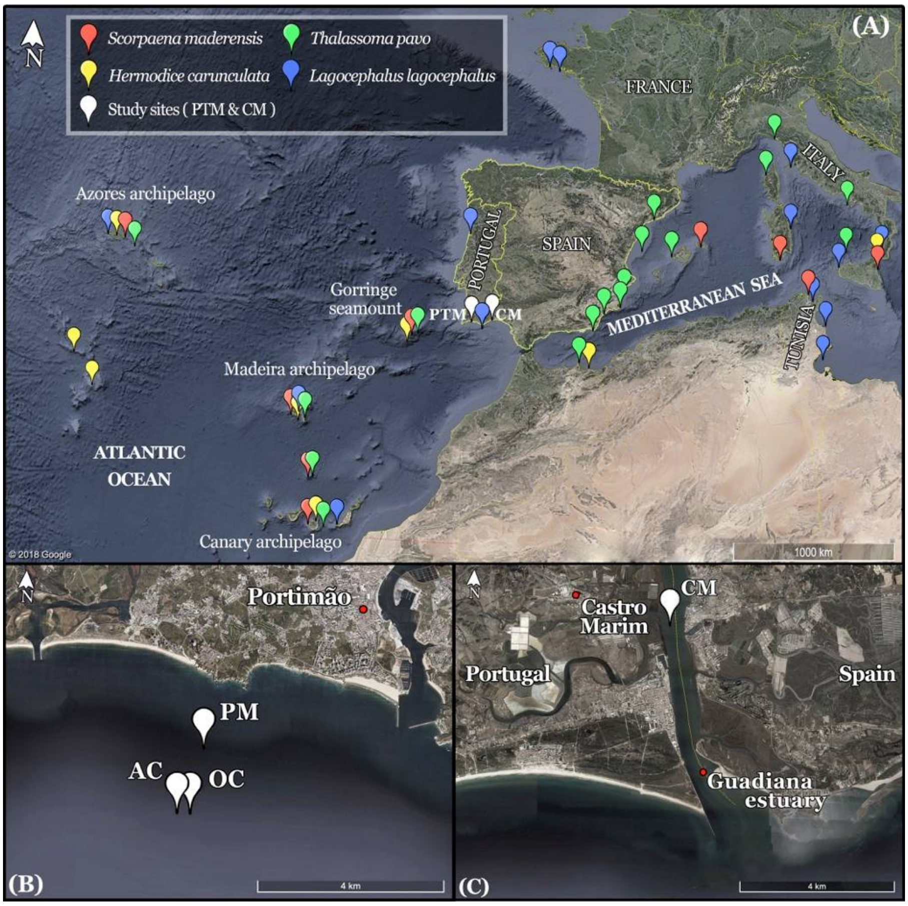

Figure 1. (A) The location of the two main study sites off Portimão (PTM) and in the lower Guadiana estuary off Castro Marim (CM) (SE-Portugal/SW-Spain) is shown in the context of the Iberian Peninsula and northern African coast. The location of the Gorringe seamount and of the three Macaronesian archipelagos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

3. Results

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

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

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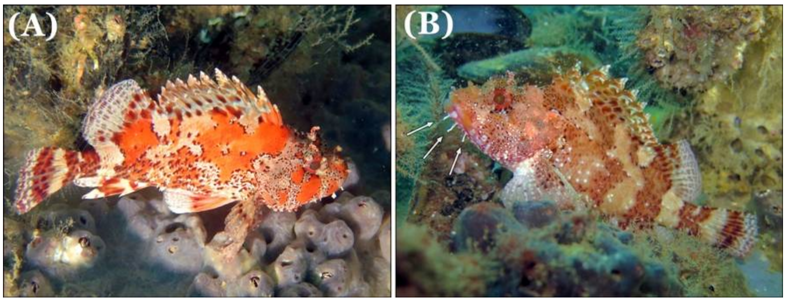

Figure 2. Photograph of Madeira rockfish *Scorpaena maderensis* (Valenciennes, 1833) on July 29th, 2016 (A) and on October 3, 2016 (B), both in the "Oliveira e Carmo" corvette. Arrows indicate the distinctive long white tentacles in the lower mandible (B).

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).

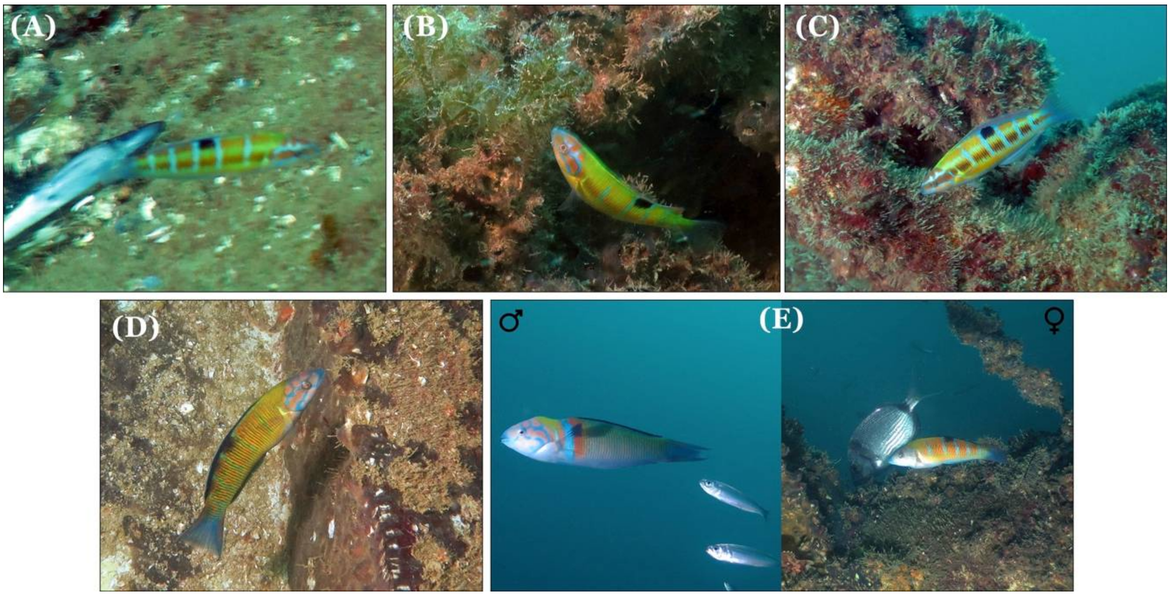

Figure 3. Photograph of ornate wrasse *Thalassoma pavo* (Linnaeus, 1758) on May 8, 2017 (A), May 31st, 2017 (B) and September 19, 2018 (C), all in the "Almeida Carvalho" hydrographic ship. A specimen observed on September 22, 2018 in the "Oliveira e Carmo" corvette (D) and on October 3, 2018, a male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

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).

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

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

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

Table 1. Morphometric and meristic characteristics, as well as the total fresh weight, of the male oceanic puffer *Lagocephalus lagocephalus* (Linnaeus, 1758) specimen collected in the lower Guadiana 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

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4. Discussion

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

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

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

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

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

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

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

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

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

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

5. Conclusions

The presence of the Madeira rockfish, ornate wrasse, and bearded fireworm off the SW-Iberian Peninsula, and possibly the presence of the oceanic puffer in the Guadiana estuary, may represent examples of poleward distribution range expansion of subtropical/tropical species. This hypothesis has support on multiple evidence from other species as described in this paper. We advocate for the implementation of systematic surveys along the Atlantic coast of the Iberian Peninsula, concomitantly with genetic analyses, to find support for the tropicalization hypothesis. We also propose that these new fish species should be monitored and included in local fisheries management plans if their abundance increases.

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