

An Update on the Invasion of Weakfish *Cynoscion regalis* (Bloch & Schneider, 1801) (Actinopterygii: Sciaenidae) into Europe

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Abstract: New information on weakfish introduction vectors, its invasive status, distribution, and use as a fishing resource arose after the publication of “The transatlantic introduction of weakfish *Cynoscion regalis* (Bloch & Schneider, 1801) (Sciaenidae, Pisces) into Europe” by Morais and Teodósio (2016). Currently, the first known report of weakfish in Europe dates back to September 2009, with a specimen captured in the Schelde estuary (Belgium/The Netherlands). This fact suggests that weakfish could have been introduced into Europe via multiple and independent ballast water introduction events, and not through a point-source introduction event with subsequent dispersion as previously hypothesized. It is also unlikely that Schelde weakfish migrated southwards to colonize Iberian aquatic ecosystems. Weakfish have established a population in the Gulf of Cádiz region and have already reached an invasive status in the Sado estuary (Portugal). Weakfish were also captured in several other locations along the Portuguese coast, including the Tagus and Mira estuaries at least since 2013 or 2014, and the Ria Formosa lagoon in 2017. Tagus anglers caught weakfish specimens of ~1 kg and ~40 cm in November 2016, which corresponds to fish of 3+ years of age in the native range. The presence of weakfish in the Tagus estuary is still fairly unknown to local anglers. Sado weakfish has already been sold in local fish markets in southern Portugal for 3 to 10 € kg^{−1}. However, we consider that the weakfish sale price is underrated in comparison with other wild species (e.g., meagre, seabass, gilthead seabream). Increasing sale price will convince fishers to use weakfish as a new fishing resource; however, it is necessary to promote the species among consumers and evaluate consumers’ preference in respect to other species. A putative biological threat might turn into a new valuable fishing resource by implementing adequate management solutions.

Keywords: biological invasions; non-indigenous species; fish; introduction vectors; ballast water; fishing resource; Iberian Peninsula

1. Introduction

Identifying the introduction vectors and sites of introduction is critical for the enforcement of adequate management strategies, to eradicate a non-indigenous species, mitigate its impacts, and prevent further introductions. The weakfish *Cynoscion regalis* (Bloch & Schneider, 1801) is one of the most recently introduced fish in Europe [1,2]. It was hypothesized that weakfish were introduced in the Sado estuary (Portugal) before 2012, via ballast water, and that individuals dispersed northwards to the Galician coast as well as southwards to the Gulf of Cádiz [2].

The role of citizen science was fundamental for Portuguese scientists in acknowledging the presence of weakfish in Portuguese aquatic ecosystems [2]. News of weakfish capture in the Guadiana estuary in June 2016 continued to provide new reports [3,4], from both scientists [5–7] and

anglers [8–12]. An update on the information and hypotheses about the introduction of weakfish into Europe is crucial to avoid the perpetuation of erroneous information, to set new hypotheses, and to propose new management solutions.

2. “Single Introduction and Dispersal” vs. “Multiple Independent Introductions”

The introduction of fish species via ballast water is uncommon, yet multiple independent introductions have been documented (Table 1). A few Gobiidae and Blenniidae species provide examples of such cases (Table 1), probably because of their crevicolous nature [13] and other biological traits that allow individuals to withstand long transport periods (e.g., larvae with large yolk-sacs).

Table 1. List of non-native fish species introduced in marine and brackish water ecosystems in multiple locations through independent events. This table is a modified and updated version of a table presented by Wonham et al. [13].

Family	Species	Native Range	Non-Native Range	Introduction Vectors	References
Gobiidae	Yellowfin goby <i>Acanthogobius flavimanus</i> (Temminck & Schlegel, 1845)	Northwestern Pacific	Northeastern and Southwestern Pacific	Ballast water	[14,15]
	Striped sand goby <i>Acentrogobius pflaumii</i> (Bleeker, 1853)	Northwestern Pacific	Southwest Pacific	Ballast water	[15,16]
	Round goby <i>Neogobius melanostomus</i> (Pallas, 1814)	Black and Caspian Seas	Great Lakes, Baltic Sea, Central European Rivers	Ballast water	[17,18]
	Tubenose goby <i>Proterorhinus semilunaris</i> (Heckel, 1837)	Black and Caspian Seas	Great Lakes, Baltic Sea, European rivers and coastal areas (France, The Netherlands, Belgium)	Ballast water	[17,19,20]
	Chameleon goby <i>Tridentiger trigonocephalus</i> (Gill, 1859)	Northwestern Pacific	Northeast Pacific, Southwestern and Southeast Australia, Mediterranean Sea	Ballast water	[14,15,21]
Blenniidae	Muzzled blenny <i>Omobranchius punctatus</i> (Valenciennes, 1836)	Indo-West Pacific	Central and Southwestern Atlantic, Mediterranean Sea	Ballast water	[22,23]
Sciaenidae	Red drum <i>Sciaenops ocellatus</i> (Linnaeus, 1766)	Northwest Atlantic	Indo-West Pacific	Aquaculture, deliberate releases	[24]

Recently, it was mentioned that the first weakfish captured in Europe occurred in the Schelde estuary (Belgium/The Netherlands) on 24 September 2009 (Figure 1) [5]. This predates the reported introduction of weakfish into Europe at the Sado (Portugal) [2] and Gulf of Cádiz regions [5] by at least three years. However, there is no information suggesting that weakfish established eastwards from the English Channel, where the minimum water temperature falls within critical ranges for this species—weakfish cease feeding and die when the water temperature reaches 7.9 °C and 3.3 °C, respectively [25,26].



Figure 1. Locations where weakfish *Cynoscion regalis* (Bloch & Schneider, 1801) (Actinopterygii: Sciaenidae) have been collected in Europe. The numbered pins are ordered chronologically concerning first known reports of weakfish captures along Europe. Please notice that first reports do not necessarily coincide with the date of introduction. Legend: 1—Scheldt estuary, September 2009 [27]; 2—Gulf of Cádiz, 2011 [5]; 3—Sado estuary, the first written report was made in September 2014, but it was noticed in the area for “some” years before [5,28]; 4—Tagus estuary, 2013 or 2014 [29]; 5—Mira estuary, 2013 or 2014 [29]; 6—Praia da Vieira, October 2015 [6]; 7—Ría de Vigo, June 2016 [30]; 8—Ría do Barqueiro, June 2016 [30]; 9—Guadiana estuary, June 2016 [2]; 10—Praia do Barranco das Belharucas, July 2016 [2]; 11—Ria Formosa [31]. Map retrieved from Google Earth.

It is unlikely that individuals introduced into the Schelde estuary dispersed southwards to colonize Iberian Peninsula estuaries without being noticed in ecosystems located between these regions. Yet, the observation made by Maarten Stevens in the Schelde estuary suggests that weakfish were introduced into Europe in different locations through ballast water [27]. The propagule pressure is enormous in the Schelde estuary because it harbors the third busiest container port in Europe (the Port of Antwerp) [32]. Available information points towards the existence of at least two viable populations in the Iberian Peninsula (SW-Europe), one in the Sado region (estuary and adjacent coast of Portugal) [2] and another in the Gulf of Cádiz region (Figure 1) [5]. The Sado estuary also has a harbor with intense traffic of transoceanic ships; it is the region with the highest number of non-indigenous marine species in Portugal [33], and the sixth busiest European transshipment port is located ~60 km southwards (the Port of Sines) [32]. The Guadalquivir estuary is located 20 km and 25 km away from two ports with international ship traffic (one US military base, one port/shipyard) (Figure 1) [5].

Thus, and contrary to what was hypothesized [2], weakfish might be a rare example of a fish species introduced through multiple and independent introduction events, with populations established in at least two regions—the Sado and the Gulf of Cádiz regions. Galician weakfish could have been introduced in the Port of Vigo or A Coruña, or they could be individuals that dispersed from southern regions (Figure 1). Individuals from each one of the established populations (Sado and Gulf of Cádiz) can disperse and colonize other estuaries and regions. For example, the few weakfish specimens collected in the Guadiana estuary [34] and Ria Formosa lagoon [31] probably originated from the Gulf of Cádiz population. Ria Formosa weakfish were caught by fishermen in the summer of 2017. The recreational fishing pressure is high in the Guadiana estuary and in the Ria Formosa lagoon, so the capture of a few specimens suggests that weakfish still do not intensively use these

ecosystems as a nursery/feeding area. Similarly, Sado weakfish are likely the source population of Tagus and Mira weakfish, whose presence dates back at least to 2013 or 2014 (Figure 1) [29].

The first written report about Tagus weakfish dates back to May 2015 (Figure 2) [6]. However, weakfish is still fairly unknown among local anglers, despite the enormous sports fishing pressure that exists. A series of informal inquiries were conducted, targeting Tagus anglers in June, July, and August 2016, and none had ever collected or knew about the capture of weakfish in this estuary [2,35]. Weakfish were collected by anglers at Alhandra on 18 September 2016; however, they misidentified weakfish as zander *Sander lucioperca* (Linnaeus, 1758) (Percidae) because they were unaware of the presence of weakfish in the Tagus or other Portuguese waters. On 12 November 2016, several other specimens were captured by anglers near the northern pillars of the Vasco da Gama Bridge, 300–400 m away from the Lisbon shore (Figure 2) [11]. These specimens weighted “a little over 1 kg” [11], and their length averaged 40 cm, which corresponds to fish 3+ years of age in the native range [36]. The depth in both sites ranges between 10 and 15 m. Alhandra is located in the freshwater tidal area of the Tagus estuary, while the Vasco da Gama Bridge area is in the mesohaline estuarine reach.

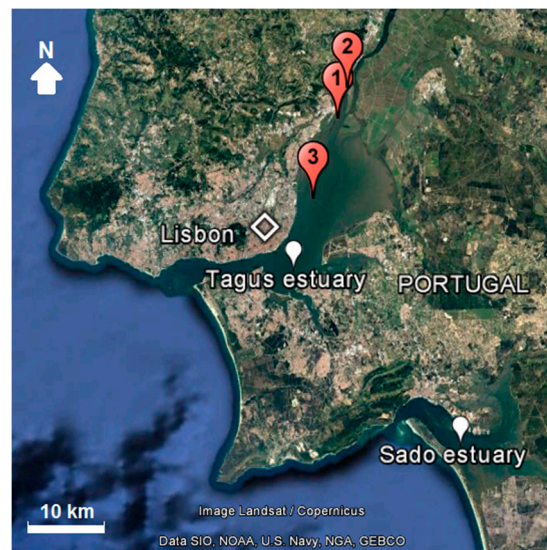


Figure 2. Locations where weakfish *Cynoscion regalis* (Bloch & Schneider, 1801) (Actinopterygii: Sciaenidae) were collected in the Tagus estuary—Alverca (3 May 2015). (1), Alhandra (16 September 2016); (2), Vasco da Gama bridge (12 November 2016); (3). Map retrieved from Google Earth.

Tagus and Mira estuaries are located ~60 km northwards, and ~90 km southwards from the Sado estuary; these distances refer to the path distance between the Sado estuary and the other estuaries. So, weakfish from these estuaries likely belong to the same metapopulation as Sado weakfish, since they perform migrations along the continental shelf before entering estuaries [37]. Weakfish use both coastal areas and estuarine ecosystems as spawning, feeding, and nursery areas [37,38], and leave estuaries during the fall when water temperatures decrease [36]. However, it is also possible for weakfish to overwinter in estuaries [39].

3. Transforming a Biological Threat into an Economic Opportunity

Controlling invasive fish populations through fishing is a challenging endeavor. One of the most iconic examples is the tentative control of red lionfish *Pterois volitans* (Linnaeus, 1758) (Scorpaenidae) in tropical and subtropical Western Atlantic Ocean, Caribbean Sea, and the Gulf of Mexico. Here, it was proposed that the substantial reduction of the population of standing stock could only be achieved locally with intense fishing pressure across several consecutive years [40,41]. It was also proposed that red lionfish could be used by local populations as a new item in their diet to mitigate the

invasion [42]. A similar proposal was made regarding the Atlantic blue crab *Callinectes sapidus* Rathbun, 1896 (Portunidae) in southern European coastal waters [43]. Still, there are several caveats which must be considered before encouraging the control of invasive species through fishing [44]. First, it is essential to know if the fishing pressure efficiently reduces the population size and growth. Second, it is advised to ensure at the onset of such a management practice that no efforts will be made to transform the fishery of an invasive species into a viable fishery to avoid false expectations by local communities that the commercial revenue from such fishery will be perpetuated [44]. Third, managers must make all efforts to educate the public on the putative negative impacts of non-indigenous species and convey that introductions into non-invaded areas are not allowed [44]. Overall, we propose that such cautionary management solutions must be applied to Sado and Gulf of Cádiz weakfish.

In the case of Sado weakfish, the species has already been sold in southern Portugal fish markets, at Olhão and Tavira for 5 € kg⁻¹, while in Setúbal the price varied between 3 to 10 € kg⁻¹. However, we believe that average prices (~5 € kg⁻¹) might not be high enough to attract fishers to target weakfish. Thus, fishers and fish vendors should take advantage of this new fishing resource by promoting their main feature (i.e., being a wild fish) to increase the selling price. The weakfish sale price is below those of any other fish with similar characteristics, either wild fish or fish reared in aquaculture. A few examples are: (a) meagre *Argyrosomus regius* Asso 1801 (Sciaenidae): 12 € kg⁻¹ for wild fish, 9 € kg⁻¹ for aquaculture fish; (b) European seabass *Dicentrarchus labrax* (Linnaeus, 1758) (Moronidae): 25 € kg⁻¹ for wild fish, 8 € kg⁻¹ for aquaculture fish; (c) gilthead seabream *Sparus aurata* Linnaeus, 1758 (Sparidae): 25 € kg⁻¹ for wild fish, 8 € kg⁻¹ for aquaculture fish [45,46].

Using weakfish as a new fishing resource has the potential to at least minimize the putative ecological impacts that they might exert [2]. However, it is still necessary to attribute a fair price tag to weakfish by promoting the species among consumers and evaluating their preference in respect to other species consumed in Portugal and Spain, either wild or aquaculture fish.

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