BioInvasions Records (2016) Volume 5, Issue 4: 259–265
DOI: http://dx.doi.org/10.3391/bir.2016.5.4.11

Open Access

Rapid Communication

The transatlantic introduction of weakfish *Cynoscion regalis* (Bloch & Schneider, 1801) (Sciaenidae, Pisces) into Europe

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Received: 28 June 2016 / Accepted: 28 September 2016 / Published online: 7 October 2016

Handling editor: Charles W. Martin

Abstract

Weakfish *Cynoscion regalis* (Bloch and Schneider, 1801) is a sciaenid fish native to the east coast of North America and has been recently collected in three areas of the Iberian Peninsula (Europe). We aimed to i) provide the first report of the presence of weakfish in Europe, ii) hypothesize the most likely introduction vector, iii) discuss the potential for ecological overlap between weakfish and meagre *Argyrosomus regius* (Asso, 1801), the native Sciaenidae species, and iv) highlight the importance of citizen science in the detection of non-native species. Weakfish were captured in the Sado estuary (July 2014), Gulf of Cadiz (November 2015) and the adjacent Guadiana estuary (June 2016), and in two Galician Rías (June 2016). Anglers reported that weakfish was present in the Sado estuary for "some" years, while their presence was only noticed recently in the other two areas. We hypothesize that ballast water was the introduction vector, that weakfish established a reproducing population in the non-native range, and that it dispersed from the Sado estuary, a central region of its current distribution range. The Sado estuary might have been the introduction area for weakfish via ballast water because there is a busy transoceanic commercial port in the estuary. Moreover, they are not used in European aquaculture facilities, nor in the aquarium trade. The collected specimens were ≤50 cm, with average lengths of 30 cm, which corresponds to a median age of 2 years and to individuals capable of reproducing. As a result, the year of introduction must be before 2012. Weakfish have a similar ecological niche to meagre, but the outcome of potential interactions is uncertain. Citizen science, especially the initiative of local fishermen, was critical to detect this non-native species.

Key words: non-native, fish, ballast water, citizen science, Portugal, Spain, Iberian Peninsula

Introduction

Reports on transoceanic marine invasions are becoming more common (Callaway et al. 2006), and they consist primarily of introductions of holoplanktonic (Berg et al. 2002) and meroplanktonic invertebrate species via ballast water (Roman 2006). In the case of vertebrates (i.e. fish), intentional introductions (e.g., for recreational fishing), escapees from aquaculture facilities (Bartley 2011 (Copp et al. 2007), and aquarium release (Brice et al. 2004) are the most common vectors of introduction rather than via ballast water (Wonham et al. 2000; Grigorovich et al. 2003; Copp et al. 2007).

The presence of weakfish *Cynoscion regalis* (Bloch and Schneider, 1801) (Sciaenidae, Pisces) in the Iberian Peninsula (western Europe) is a recent example of a transoceanic marine fish introduction. This species is native to the east coast of North America (Froese and Pauly 2016), was detected by fishermen in several regions of the Iberian Peninsula and subsequently announced in specialized magazines (Mundo da Pesca 2016), personal blogs (OsPescas 2015), and regional online media (e.g., A Voz do Algarve 2016; Europapress 2016; Vigoe 2016). The native distribution of weakfish is from Florida's Atlantic coast (USA) to Nova Scotia (Canada), where it is exploited in commercial and sport fisheries (Froese and Pauly 2016; NMFS 2016). In Europe, the meagre *Argyrosomus regius* (Asso, 1801) is the most abundant Sciaenidae species. The meagre is a valuable species for local and artisanal fisheries and sport fishing, and it is also reared in aquaculture (Mañanós et al. 2009; Duncan et al. 2013).

Weakfish and meagre share several ecological traits (e.g. habitat use, reproduction period, diet) (Froese and Pauly 2016) so their fundamental niche might overlap where they now co-occur in the Iberian Peninsula. In this paper we: i) provided the first scientific report of weakfish in Europe; ii) described the putative introduction vectors; iii) discussed the potential ecological overlap between weakfish and meagre; and iv) highlighted the importance of citizen science in the detection of non-native species.

Material and methods

Study area

The Guadiana River estuary is a mesotidal estuary with an average depth of 6.5 m, occupying an area of 22 km^2, and the tidal amplitudes range from 1.3 to 3.5 m. The estuary drains into the Gulf of Cadiz (Atlantic Ocean), extends inland for 70 km, and the last 50 km serve as the southern border of Portugal and Spain (Iberian Peninsula, Europe) (Figure 1). The Guadiana River flow varies substantially within and among years because of variations in rainfall. However, after the completion of the Alqueva dam in February 2002, the river discharge is usually lower than 20 m^3 s^{-1} (Garel and Ferreira 2011), despite episodic flooding events (e.g. March–April 2013).

Capture, identification, and distribution of weakfish in Europe

One adult weakfish was collected in the Guadiana estuary (SW-Iberian Peninsula) (Figure 1) using longline fishing gear as part of a routine commercial fishing operation. The longline was set in the estuary 11 km upstream from the river mouth (37º15′33″N; 7º25′55″W) during the night of 15 June 2016 and retrieved 12 hours later. The identification of the specimen was made according to Bigelow and Schroeder (1953). The total length (TL, ±0.1 cm) and total fresh weight (TFW, ±1 g) were determined, and the meristic characteristics recorded: fin rays, gill rakers, and lateral line scales.

After the identification of the specimen, we established several contacts with fishermen and scientists and also did online searches (in Portuguese, Spanish, French, and English) to verify the existence of previous records of this species in Europe. Then, we made a press release (in Portuguese) announcing the collection of weakfish in the Guadiana estuary to reach a broad audience and get feedback from the general public about the presence of this species in Portugal.

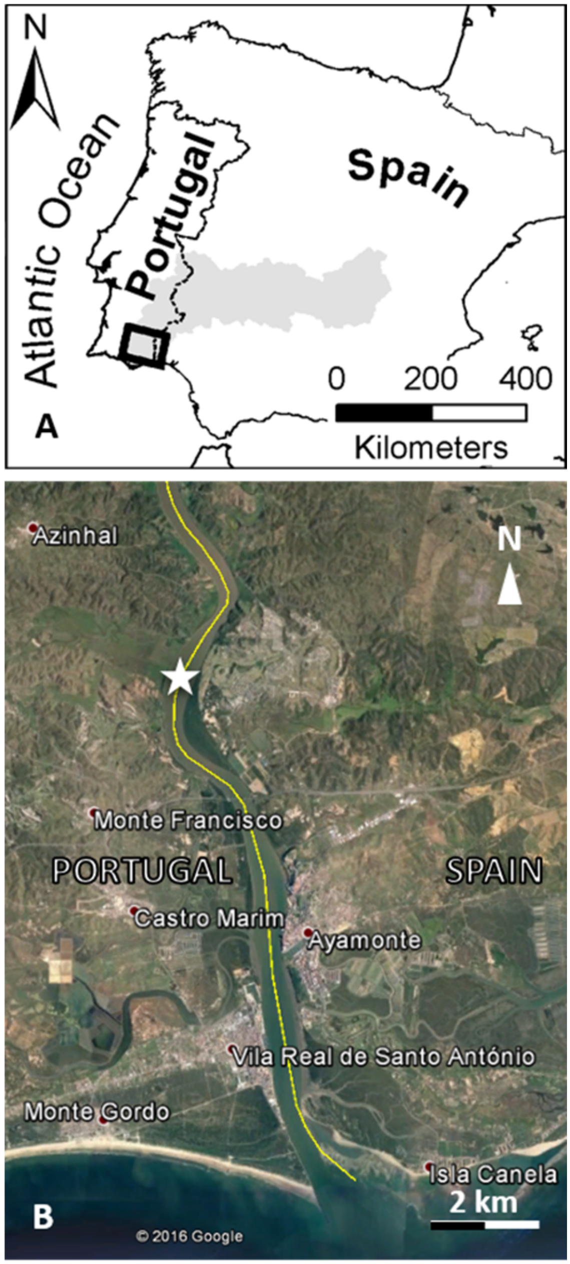

Figure 1. Map of the Iberian Peninsula indicating the Guadiana River basin (A) and location where the specimen of weakfish *Cynoscion regalis* was collected in the Guadiana estuary on 16 June 2016 (white star) (B).

Results

The morphological characteristics of the specimen we obtained from the Guadiana estuary, based dorsal pigmentation and dorsal fin pigmentation (Figure 2), allowed its identification as weakfish *Cynoscion regalis*. This specimen measured 32.6 cm TL and

Figure 2. The specimen of weakfish *Cynoscion regalis* collected in the Guadiana estuary on 16 June 2016 (A), and detailed photos of the head and operculum (B) and of the pigmentation pattern in the dorsal area and second dorsal fin (C). Scale bars: 1 cm. Photographs by Pedro Morais.

Table 1. Meristic characteristics of the weakfish specimen collected in the Guadiana estuary, on 16 June 2016, of weakfish from its native area on the east coast of North America and of meagre. Meristic data for North American weakfish is from Tagatz (1967) and Froese and Pauly (2016), while meagre meristic data is from Chao (1986) and Dulčić et al. (2009).

	Guadiana weakfish	North America weakfish	Meagre
Dorsal fins rays	D_1 X, D_2 I+27	D_1 X, D_2 I+24–29	D_1 IX–X, D_2 I+26–29
Pectoral fin rays	18	–	16
Pelvic fin rays	5	–	I–5
Anal fin rays	II+11	II+10–13	II+7–8
Caudal fin rays	17	–	–
Gill rakers	5+12	4–5+10–12	–
Lateral line scales	78	76–86	53

weighed 381 g TFW. The meristic characteristics of the specimen fell within the range described for the species in its native North American range (Table 1).

As of 24 June 2016, there were three online media reports of weakfish in Europe. Weakfish were reported for the first time in regional online media in February 2016 when mention was made of their capture in the Gulf of Cadiz (SW-Iberian Peninsula) in November 2015 (Europapress 2016). These specimens were collected by fishermen and identified by A Arias, J Cuesta, and R Bañón (R. Bañón, Grupo de Estudo do Medio Mariño, Spain, pers. comm.). The fish from the Gulf of Cadiz ranged between 28 cm and 33 cm TL although there were unsubstantiated accounts of fish of almost 50 cm TL (Vigoe 2016). The capture of weakfish in two Galician Rías (Ría de Vigo and Ría O Barqueiro) was reported on 20 June 2016 (Vigoe 2016). These fish ranged between 26 cm and 32 cm TL. The capture of the Guadiana weakfish (our specimen) was reported by regional media on 23 June 2016 (A Voz do Algarve 2016), and posted on social networks (CCMAR 2016). As a result of the media coverage, anglers came forward with information that weakfish were present in the Sado estuary (west coast of Portugal) for "some" years (C Morais, P Santos, Portugal, pers. comm.). The first online posting about weakfish in Sado estuary including a photograph of the fish was made in a personal blog on 24 September 2015 (OsPescas 2015). The Sado weakfish was similar in size to that from the Guadiana estuary. Other weakfish were caught by anglers in June and July 2016, one in the southern coast of Portugal at Barranco das Belharucas Beach (Olhos de Água county) on 5 June 2016 (E Pedro, pers. comm.) and two in the Sado estuary (27 and 28 July 2016) (OsPescas 2015). Later on, an anglers magazine also covered the report of weakfish in the Guadiana estuary, and stated that they mentioned the presence of weakfish in the Sado estuary in July 2014 (Mundo da Pesca 2016).

Discussion

Weakfish in Europe

Hanel et al. (2009) described the occurrence of seven Sciaenidae species along the European coastline and adjacent seas: *Argyrosomus regius* (Asso, 1801), *Cynoscion nebulosus* (Cuvier, 1830), *Pseudotolithus senegalensis* (Valenciennes, 1833), *Sciaena umbra* Linnaeus, 1758, *Umbrina canariensis* Valenciennes, 1843, *Umbrina cirrosa* (Linnaeus, 1758), and *Umbrina ronchus* Valenciennes, 1843. Our reporting of *Cynoscion regalis* in the Iberian coast raises the number of Sciaenidae in Europe to eight, and the second native to the northwestern Atlantic—the other species present is spotted seatrout *Cynoscion nebulosus* (Froese and Pauly 2016). Weakfish distribution in the Iberian coast encompasses ~800 km of coastline, from Galicia (Vigoe 2016) to the Gulf of Cadiz (Europapress 2016); however, it was reported from only five sites—Rías de Vigo and O Barqueiro in Galicia, Sado estuary, Gulf of Cadiz and the adjacent Guadiana estuary.

First reports of weakfish in the Iberian Peninsula date back to July 2014 (Mundo da Pesca 2016) but the year of introduction was likely before 2012, as anglers mention that weakfish were collected in the Sado estuary for “some” years before being described in a magazine devoted to recreational angling (OsPescas 2015; Mundo da Pesca 2016). Weakfish of approximately 30 cm TL are 1–2 years old, while fish of 50 cm are 2–3 years old (Hatch 2012). Thus, weakfish spent at least 3–4 years without being noticed by the scientific community in the Iberian Peninsula. The potential expansion of weakfish to the northern European coast and adjacent seas will likely be controlled by water temperatures because they cease feeding at 7.9 °C and die at 3.3 °C in the native range (Bigelow and Schroeder 1953). Thus, weakfish has the potential to expand its range in Europe up to the English Channel, to the Irish Sea and the western coast of Scotland, where winter water temperature coincides with their cease-feeding temperature (SeaTemperature 2016).

Introduction, establishment, and dispersion

Aquarium and/or aquaculture release are unrealistic introduction vectors for weakfish because the species is not used in the aquarium trade or in Portuguese and Spanish aquaculture practices (Laura Ribeiro and Pedro Pousão Ferreira, Instituto Português do Mar e da Atmosfera, person. comm.). So, we hypothesize that ballast water was the most likely vector of weakfish introduction in Europe. The short duration of transoceanic ship travel between the east coast of North America and the western Iberian Peninsula coast (e.g. nine days, SeaRates 2016), and the physiological plasticity of weakfish larvae and young-of-the-year (i.e. present in the inner continental shelf and in the brackish and oligohaline estuarine sites) (Able and Fahay 2010) suggests that weakfish were able to circumvent ballast water exchange regulations. Ballast water management guidelines include practices that minimize the uptake of organisms and sediment into ballast tanks at the port of origin, exchange of ballast water at sea, and the discharge of water to shore reception facilities at the port of destination, treatment and even the non-release of ballast water (IMO 2016).

Assuming that the introduction via ballast water is possible, then there are two main hypotheses that could explain the apparent establishment of weakfish in the Iberian Peninsula shores. Weakfish may form a population that does not reproduce in Europe, but mantain its presence through continuous and successful introductions via ballast water; alternatively, the species is able to reproduce in the non-native range. The validation of these hypotheses minimally requires the collection of ichthyoplankton samples to detect their presence (or not), and analysis of gonadal tissues from adult fishes. However, the size of the individuals collected and its broad distribution range suggest that weakfish reproduce in the non-native range.

Weakfish are present in three Iberian regions, with the extreme regions separated by ~800 km of coastline. This fact suggests that the introduction of weakfish occurred in either: a) three distinct regions with subsequent establishment of three localized populations; b) one region located in one of the extreme regions of distribution (Gulf of Cadiz or Galicia) and subsequent dispersion; or c) one central area with subsequent establishment and dispersion. The first hypothesis is the least likely since the establishment of fish after their introduction through ballast water is unusual (Wonham et al. 2000). Thus, the introduction and establishment of weakfish in a specific region and its subsequent dispersion and establishment in other areas seems to be the most feasible scenario. Based on the available information, we hypothesize that the Sado estuary was the introduction site as it is the region with the highest number of non-indigenous marine species in Portugal (Chainho et al. 2015) and the first report on the presence of weakfish dates back to July 2014. Three main factors contribute to this hypothesis. First, local anglers mentioned the presence of weakfish for "some" years in the Sado estuary. Second, this estuary has a harbor with the intense traffic of transoceanic ships, which increases propagule pressure. Lastly, the Sado estuary and adjacent coastal area is a highly productive ecosystem with adequate abiotic conditions to enhance fish survival and growth (Lankford and Targett 1994; Able and Fahay 2010) and could allow the establishment and subsequent transport and migration of weakfish larvae and adults to other regions.

Ecological overlap between weakfish and meagre

Weakfish and meagre share several ecological characteristics, including: feeding upon similar types of prey (e.g. fish, penaeid and mysid shrimps, crabs, amphipods, clams, annelids); using estuaries as nurseries during the same period (from spring until late summer and early autumn); and seeking protection in holes and deep channels (Bigelow and Schroeder 1953; Froese and Pauly 2016). However, they differ in longevity, maximum size and weight, time of the first maturity and fecundity. Weakfish usually live 9–12 years, although the oldest fish reported was 17 years old (Lowerre-Barbieri 1994). Most fish are <98 cm and <8.9 kg (Froese and Pauly 2016). Meagre can live to 44 years (Prista et al. 2009) and reach 2.3 m and 103.0 kg (Froese and Pauly 2016). Weakfish mature at an early age. For example, in North Carolina, 52% of females and 62% of males mature at age 0, and at age 1 all females >17.5 cm are mature, and fecundity can reach 5.0 million eggs for a fish of 57 cm (SL) (Merriner 1976). In contrast, the first sexual maturity of male and female meagres is at 45 cm and 47 cm, respectively (~2 years old) (Abou Shabana et al. 2012), while fecundity ranges between 2.1–31.1 million eggs for females with sizes ranging from 1.0–1.7 m (Gil et al. 2013).

It seems the native meagre would have an advantage over weakfish because it grows to a larger size, its fecundity is up to 6.2× higher, and weakfish larvae and juveniles can eventually serve as prey to meagre. However, weakfish mature sooner, and might acquire higher fitness if they are able to leave their parasites behind (i.e. enemy release hypothesis) (Torchin et al. 2001) after their introduction in the Iberian Peninsula coast. Thus, given the lack of knowledge about meagre ecology during their estuarine phase (e.g. abundance, feeding habits, realized niche), plus the uncertainties about the outcome of competition between meagre and weakfish (coexistence in the same habitats, exclusion of meagres, dominance of meagres over weakfish and thus controlling weakfish invasion success) and the economic importance of meagre in the Guadiana estuary, at least since the 18^{th} century (de Lacerda Lobo 1815), we recommend the establishment of a monitoring program for these two Sciaenidae species in the Gulf of Cadiz and adjacent estuarine nursery areas.

Citizen Science

The putative introduction of weakfish in the Sado estuary, perhaps earlier than 2012, suggested that the species had gone unnoticed by the Portuguese scientific community. Recent budget cuts made by the Portuguese government can only explain part of this lack of awareness since this could have been circumvented with effective communication strategies between scientists and the general public. Indeed, citizen science has shown its utility in the detection of non-native and cryptic invasive species in a way that would be impossible to be made solely by scientists or at exorbitant costs (Epps et al. 2014; Scyphers et al. 2015). For example, the detection of weakfish in the Iberian Peninsula was only possible due to fishermen's contributions. This initial awareness pressures the scientific community to establish more efficient means of communication with the public to allow the detection of non-native species and other ecological threats. The use of new smartphone technologies, social media platforms, and other applications is a path that needs to be further explored. Applications allowing the upload of a species photograph to alert a group of specialists (after determining whether the specimen is a plant- or animal-like specimen, or aquatic or terrestrial specimen) could aid in the detection of non-native species. Ideally, this could allow the establishment of more efficient programs of species control or eradication, and ultimately help to determine their suitability for commercial exploitation (e.g. food consumption, biomedical active compounds).

The dialogue between aquatic scientists and the general public has to acknowledge and promote the "Research Responsible and Innovation" concept, which proposes that the research questions should be derived from societal problems and formulated with their collaboration and thus responding to their concerns (European Commission 2016). For example, scientific workshops on non-native species can demonstrate that scientists can assist local communities in tackling this issue and also explore new business opportunities, while scientists increase the temporal and spatial resolution of long-term monitoring programs of aquatic ecosystems. Aquatic invasions scientists need to implement more efficient ways of communication with society, especially with local fishermen, to facilitate earlier detection of non-native species and other ecological problems that affect aquatic ecosystem services with negative potential social and economic consequences.

Acknowledgements

We thank A Fernandes and J Estica for giving us the first specimen of weakfish collected in the Guadiana estuary and J Babaluk for proof-reading the paper. C Morais, E Pedro, and P Santos provided information on the capture of weakfish in Portugal. R Bañón (Grupo de Estudo do Medio Mariño, Spain) provided information on the identification of weakfish in Spain, while L Ribeiro and P Pousão Ferreira, both from "Instituto Português do Mar e da Atmosfera", provided information on the aquaculture of Sciaenidae in the Iberian Peninsula. MAT was funded by Foundation for Science and Technology (FCT, Portugal) through a sabbatical fellowship (SFRH/BSAB/113684/2015) and by the European Regional Development Fund (COMPETE program-Operational Competitiveness Programme), and by national funds from FTC through project UID/Multi/04326/2013. We also thank three anonymous reviewers, CW Martin and JM Hanson for their suggestions on how to improve the initial versions of this paper.

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Note

After this paper was accepted and printed online, we were informed by Dr. Rafael Bañón (Grupo de Estudo do Medio Mariño, Spain) of one paper recently published (early October 2016) and another that is *in press*. These are: i) Béarez P, Gabriel S, Dettai A (2016) Unambiguous identification of the non-indigenous species *Cynoscion regalis* (Sciaenidae) from Portugal. *Cybium* 40: 245–248; and 2) Bañón R, Arias A, Arana D, Cuesta JA (*in press*) Identification of non-native *Cynoscion* species (Perciformes: Sciaenidae) from the Gulf of Cádiz (South of Spain) and data about its current status. *Scientia Marina*. We thank Dr. Bañón for bringing these papers to our attention.