What's for Dinner? Assessing the Value of an Edible Invasive Species and Outreach Actions to Promote Its Consumption

Inês Cerveira
CCMAR: Centro de Ciencias do Mar
Vânia Baptista
CCMAR: Centro de Ciencias do Mar
Maria Alexandra Teodósio
CCMAR: Centro de Ciencias do Mar
Pedro Morais (pmorais@ualg.pt)
CCMAR: Centro de Ciencias do Mar https://orcid.org/0000-0002-0861-5566

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What's for dinner? Assessing the value of an edible invasive species and outreach actions to promote its consumption

Inês Cerveira, Vânia Baptista, Maria Alexandra Teodósio, Pedro Morais*

CCMAR – Centre of Marine Sciences, University of Algarve, Campus de Gambelas, 8005-139 Faro, 8005-139 Faro, Portugal.

* Corresponding Author: pmorais@ualg.pt

Promoting the consumption of edible aquatic invasive species has gained popularity to minimize its impacts while easing pressure on native resources. Weakfish *Cynoscion regalis* (Bloch & Schneider, 1801) is one of the most recent invasive fish species in the Iberian Peninsula (Europe) which once sustained an important fishery in the native range (Northwest Atlantic Ocean). Portugal ranks third in the list of the world's top fish consumers, so promoting a weakfish fishery could at least help minimize the impacts upon native species, since weakfish have innate traits that are likely appreciated by Portuguese fish consumers. However, introducing a new species to consumers is challenging owing to consumers' habits and unfamiliarity with the species. So, we aimed to (i) evaluate the acceptance of weakfish by a panel of Portuguese fish consumers and (ii) create outreach actions – partnerships with local Chefs and press releases – to explain to a broader public what invasive species are and promote the consumption of edible aquatic invasive species. The survey that we conducted to Portuguese fish consumers showed that weakfish has great chances of being well accepted by the public – 90% of consumers would buy weakfish because they appreciated its appearance, flavour, and texture, besides being a wild fish. The outreach actions reached a few million people because 46 online articles were published, and three news pieces broadcasted on national television. Overall, our strategy greatly increased the public's awareness about invasive species, which can be replicated elsewhere in the world.

KEYWORDS weakfish, invasive species, aquatic invasions, commercial fishery, outreach, media.

Introduction

The eradication of aquatic invasive species is most often impossible (Vander Zanden and Olden 2008, Havel *et al.* 2015) and may require a continuous effort to keep the populations of some invasive species under control through time (Vander Zanden *et al.* 2010, Simberloff (2020). Invasive species benefit from a wide array of competitive advantages compared to native species, including the absence of predators and naïve prey (Colautti *et al.* 2004). In our globalized world, several species are overexploited in the native range but invasive elsewhere. This sparked the idea to use humans, the Earth's top predator, to control edible invasive species (Roman 2006; Nuñez *et al.* 2012; Lai 2015; Orth *et al*. 2020). The consumption of invasive species has become popular in the United States as a means to control the invasive lionfish *Pterois volitans* (Linnaeus, 1758) and *Pterois miles* (Benett, 1828) through a campaign whose slogan was "Eat the lionfish" (NOAA 2011), and through the publication of the cookbook *The Lionfish Cookbook: The Caribbean's New Delicacy* (Ferguson and Akins 2010).

Several chefs all over the world endorsed a similar approach with other invasive species. Chef Bun Lai from Miya's Sushi restaurant (Connecticut, USA) wants to convince the world that invasive species can be delicious, like the Asian sea squirt *Styela clava* Herdman, 1881, European green crab *Carcinus maenas* (Linnaeus, 1758), and earthworms, among many others (Lai 2015). In the UK, celebrity Chef Gordon Ramsey featured the Chinese mitten crab *Eriocheir sinensis* H. Milne-Edwards, 1853, captured in the Thames river in one of his TV shows (Ramsey 2009). The Eastern grey squirrel *Sciurus carolinensis* Gmelin, 1788 was included in the seasonal menu of "The Jugged Hare" restaurant in London to promote its consumption while advocating for the conservation of the European red squirrel (Hyslop 2015). In the United States, invasive Asian carps –

bighead carp *Hypophthalmichthys nobilis* (Richardson, 1845), black carp *Mylopharyngodon piceus* (Richardson, 1846), grass carp *Ctenopharyngodon Idella* (Valenciennes, 1844), silver carp *Hypophthalmichthys molitrix* (Valenciennes, 1844) – were introduced in the 1970s to control algae, weeds, and parasites in aquatic farms and canal systems and escaped into the Mississippi River Basin where they established breeding populations (NPS 2021). In the following years, they were fished to provide food to people facing economic problems through the campaign *Target Hunger Now!* (McCloud 2011). In Portugal, there are also examples of invasive species being used in gourmet cuisine, as the Atlantic blue crab in the Check-in restaurant (Check-in 2021) or weakfish in the São Gabriel restaurant (Evasões 2018) both owned by Chef Leonel Pereira.

Fishing invasive species to minimize their ecological impacts might be more effective in countries with higher fish consumption rates, like Portugal, which ranks third in the list of world fish consumers (EUMOFA 2016). On average, the Portuguese eat more than 55 kg of fish *per capita* in one year, twice the European Union's average (EUMOFA 2016). Most seafood consumed in Portugal is sold fresh, without being processed or preserved (Almeida *et al.* 2015). Fresh seafood requires constant supply and various other means to guarantee the fish quality, which would be unfeasible to sustain without consumers being willing to pay a higher price. Also, 63% of the consumed fish in Portugal is imported, 35% is fished locally, and only 2% is produced in national aquaculture facilities (WWF 2017). Portuguese consumers prefer wild species to farm-reared species (Cardoso *et al.* 2013; Fernandes 2017), often due to consumers' skepticism about aquaculture which mostly relies on preconceived ideas that farmed fish is of lower quality (Ramalho and Dinis 2011). All these aspects could play in favor

when introducing a new wild fish species into the Portuguese food market. But what if this new species is an invasive species?

Weakfish *Cynoscion regalis* (Bloch & Schneider, 1801), a species native from the Northwestern Atlantic, is one of the most recent introduced fish in the Iberian Peninsula (Europe) where it has established at least one viable population (Morais and Teodósio 2016; Morais *et al*. 2017) and reached an invasive status in the Sado estuary at least since 2012 (MundoDaPesca 2014) (Figure 1).

In the native range, weakfish supported local fisheries at least since the late 1800s (ASMFC 2016) but the stock is depleted since 2003 (ASMFC 2016). Overfishing and increased natural mortality observed since the mid-1990s has led the stock to depletion, despite the efforts made by the Atlantic States Marine Fisheries Commission to recover it (ASMFC 2017). In 2015, the last year for which weakfish price data is available, the average retail price was 3.95 US$ kg^{-1} (or 3.26 € kg^{-1} – Fissues 2019). However, 3-pound (1.36 kg) fresh weakfish were being sold online for 36.40 US$ (26.76 US$ kg^{-1} or 22.05 € kg^{-1}) (Fultonfishmarket 2019). In the invasive range, weakfish has been sold for 3 to 10 € kg^{-1} in Setúbal's fish market – the main city along the Sado estuary (Figure 1) – depending on the size of the fish. Similar sized wild native species, like meagre, European seabass, and gilthead seabream were sold for no less than 12 € kg^{-1}, 25 € kg^{-1}, and 25 € kg^{-1}, respectively. Although Portugal is among the world's top seafood consumers (WWF 2017), there is resilience in trying new seafood product but that can be broken by promoting species' positive attributes (e.g., health benefits, environmental protection, origin) (Sanjuán-López *et al.* 2011; Nuñez *et al.* 2012) and providing information that familiarizes the customer with the new species.

102 Thus, the main objectives of this work were to (1) evaluate the potential of
103 weakfish as a new fishing resource by evaluating consumers' receptivity to this new fish
104 species, and (2) put into practice public outreach actions (food tasting sessions, social
105 media outreach, and press releases) to increase the public's knowledge on aquatic
106 invasive species and promote the consumption of an edible aquatic invasive species.
107 This was accomplished by providing weakfish specimens to a panel of Portuguese
108 consumers to evaluate their opinion on the fish. In parallel, we undertook several
109 awareness events to inform the public about invasive species (e.g., negative impacts
110 exerted by aquatic invasive species on ecosystems; benefits of removing invasive species
111 from the environment) and raise awareness about the benefits of consuming weakfish
112 to transform an environmental menace into a source of new income to the local
113 economy. The hypotheses that we tested were three: (1) Portuguese consumers'
114 evaluation of weakfish appearance, flavor, and texture is likely to be positive; (2)
115 consumers' positive evaluation about weakfish may lead them to buy this species in the
116 future and pay a fair price, and (3) consumers are more likely to prefer wild native fish
117 species over weakfish, but weakfish over farmed native or imported fish species even if
118 sold at the same price.
119

120 **2. Materials and methods**

121 **2.1. Consumers' survey**

122 A total of twenty-four specimens of weakfish *Cynoscion regalis* (Bloch &
123 Schneider, 1801) were bought at the Setúbal fish market in June 2017 (Figure 1), and
124 given to a panel of 30 consumers that cooked the fish in their homes. The fish were
125 provided fresh and without gut contents. Consumers were chosen among the volunteers

gathered for this survey considering their gender and age group (young adults: 18-29, adults: 30-55, senior adults: >55). Each consumer replied to a survey containing ten questions (Figure 2). In questions 6 through 9, consumers were asked to compare weakfish against other species, and we used their common Portuguese names which corresponded to the following species: Atlantic horse mackerel *Trachurus trachurus* (Linnaeus, 1758), Atlantic salmon *Salmo salar* Linnaeus, 1758, European flounder *Platichthys flesus* (Linnaeus, 1758), European seabass *Dicentrarchus labrax* (Linnaeus, 1758), European pilchard *Sardina pilchardus (Walbaum, 1792)*, gilt-head seabream *Sparus aurata* Linnaeus, 1758, meagre *Argyrosomus regius* Asso, 1801, and weakfish *Cynoscion regalis* (Bloch & Schneider, 1801).

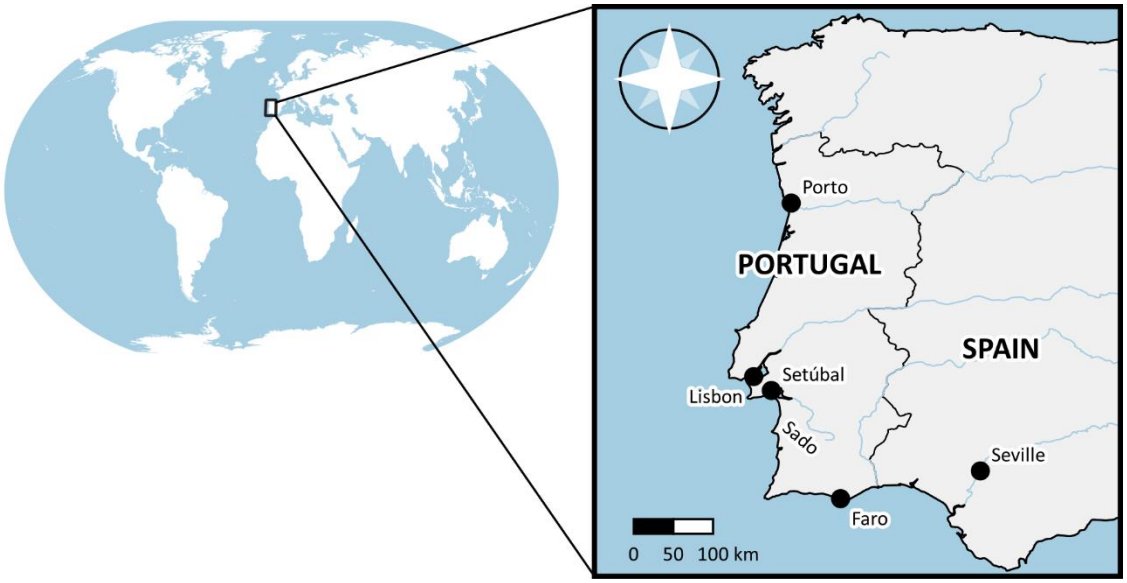

Figure 1. Location of Setúbal (Portugal) and the Sado estuary in Portugal (Europe).

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THE WEAKFISH SURVEY

This survey is being conducted by Inês Cerveira, as part of her Master Thesis in Marine Biology at the University of Algarve. The thesis' title is "Weakfish *Cynoscion regalis* (Pisces: Sciaenidae) (Bloch & Schneider, 1801) ecology in its non-indigenous range and its potential as a new fishing resource" and the advisors are Dr. Pedro Morais and Professor Maria Alexandra Teodósio.

Name _____ **Age** _____ **Contact** _____

Question 1 Please provide a general assessment about weakfish's appearance, flavour, and flesh texture.

	Bad	Indifferent	Good
Appearance	☐	☐	☐
Flavour	☐	☐	☐
Texture	☐	☐	☐

Question 2 Please mention which cooking technique you used to cook weakfish.
Boiled ☐ Grilled ☐ Roasted ☐ Fried ☐ Other ☐

Question 3 Would you buy weakfish from the market? Yes ☐ No ☐

Question 4 How much would you pay for weakfish? _____

Question 5 What would be a fair price to pay for a wild fish as weakfish? _____

Question 6 Do you prefer wild weakfish ☐ or other wild fish as gilthead seabream ☐, seabass ☐, or meagre ☐?

Question 7 Do you prefer wild weakfish ☐ or other fish produced in aquaculture as gilthead seabream ☐, seabass ☐, or meagre ☐?

Question 8 For the same price, would you rather buy wild weakfish or other fish produced in aquaculture as gilthead seabream ☐, seabass ☐, or meagre ☐?

Question 9 Order the following fish from 1 (favorite) to 7 (least favorite) according to your culinary preferences.
flounder ☐ gilthead seabream ☐ horse mackerel ☐
meagre ☐ salmon ☐ sardine ☐ weakfish ☐

Question 10 Do you prefer wild fish ☐ or aquaculture fish ☐?

Thank you for your collaboration!

Figure 2. The *Weakfish Survey* was delivered to a panel of 30 Portuguese consumers to evaluate their opinion on weakfish *Cynoscion regalis* (Bloch & Schneider, 1801), as well as their preference between weakfish versus several wild and aquacultured fish.

144 Data from this survey were analyzed with a Chi-square test after assessing the
145 test's assumptions – i.e., normal distribution and heteroskedasticity. When the
146 assumptions were not met, we used the analogous non-parametric test, the Wilcoxon
147 Signed-Rank test. All statistical analyses were done using R (version 3.4.2). Statistical
148 significance was set at 0.05.
149

150 **2.2. Outreach**

151 We promoted a series of awareness events with two objectives, (1) share
152 information about invasive species (i.e., introduction pathways, impacts, control,
153 culinary use) and (2) promote weakfish as a fishery resource as a means to mitigate the
154 putative impacts of this invasive species. So, we partnered up with two Chefs that
155 prepared weakfish in their kitchens to assess their potential as a culinary delicacy. We
156 then submitted two press releases through CCMAR's communication department about
157 these events to raise the awareness of invasive species and weakfish to a broader
158 audience. Simultaneously, we published social media content on the Centre of Marine
159 Sciences (CCMAR) Facebook page about these initiatives.
160

161 **2.2.1. Partnerships with local Chefs**

162 The first event that we organized consisted of a lunch held on September 19th,
163 2017, in Loulé (Algarve) at the canteen of Algarve Mental Health Association. Here, Chef
164 Avelino Falé prepared weakfish for teachers, technical, support, and maintenance staff
165 that eat daily at the canteen (Figure 3). The second event was hosted by "Sea" Chef
166 Leonel Pereira, owner of the Michelin star restaurant *São Gabriel* in Almancil (Algarve),
167 who was enthusiastic to test emblematic marine resources (CCMAR 2019), as weakfish

recipes in his experimental kitchen *Creative Cook Garage*, along with another edible invasive species that is not consumed in Portugal, the hydrozoan *Blackfordia virginica* Mayer, 1910 (Hydrozoa) (Figure 4).

Figure 3. Tasting session at Algarve Mental Health Association (ASMAL) canteen. Chef Avelino Falé and his staff (ASMAL's students) (left) who prepared the weakfish served at ASMAL – roasted weakfish and potatoes with red bell peppers (right).

Figure 4. Image posted by Chef Leonel Pereira on Instagram about his experiments with weakfish at his experimental kitchen in the São Gabriel restaurant (Creative Cook Garage 2018).

2.2.2. Press releases

The Centre of Marine Sciences' communication department published, on our request, two press releases in September 2017 to announce the tasting session that occurred at the Algarve Mental Health Association canteen and detailed information about two non-indigenous species present in the Guadiana estuary, weakfish and the Atlantic blue crab *Callinectes sapidus* Rathbun, 1896 (Decapoda). These press releases were published on the research centre's website and Facebook (CCMAR 2017a, b), and sent to the press using a list with more than two hundred contacts – including LUSA (the largest news agency in Portugal) and the main Portuguese television networks, newspapers, and radio stations.

2.2.3. Evaluating outreach impact

We conducted an extensive internet search to evaluate the impact of the two press releases. The impact was measured by assessing the number of articles published and interviews that were broadcasted since it is impossible to determine how many people read or view each news piece. The internet search was performed on March 28, 2018, using Google. We used a combination of keywords, both in English and Portuguese, singular and plural, and referring to the non-indigenous species described in the press releases (i.e., espécie invasora, corvina, corvina americana, corvinata, rainha, weakfish, *Cynoscion regalis*, caranguejo, caranguejo-azul, blue crab), the research institute (i.e., Centro de Ciências do Mar, CCMAR), the university (UALG, Universidade do Algarve), the study sites (Guadiana, Algarve, Portugal), and two of the scientists of this project (Maria Alexandra Teodósio, Inês Cerveira).

Three months after the two press releases, the Portuguese news agency LUSA interviewed us, along with Chef Leonel Pereira, to explain the reasons for the appearance of invasive species in Portuguese estuaries, their potential for commercial exploitation, and as a culinary delicacy. The interview was held on December 30, 2017, and published as a digital article with an audio file with a total duration of 6'40'' (LUSA 2017). A similar online search was conducted applying the methodology described above but now adding a new set of keywords (i.e., siri, medusas, alforrecas, Algarve, Restaurante São Gabriel, Chef Leonel Pereira).

3. Results

3.1. The Weakfish Survey

A total of 30 valid consumer surveys were obtained, 70% were women and 30% men (Figure 5A). The average age of the consumers was 45 ± 18 years distributed similarly across three age groups – young adults- 18 to 29 years old, adults- 30 to 55 years old, senior adults- over 55 years old (Figure 5B). The youngest and oldest consumer was 22 and 78 years old.

The majority of consumers rated weakfish appearance as good (97%, χ^2= 114.0, df= 2, p< 0.05), as well as it's flavor (90%, χ^2= 144.67, df= 2, p< 0.05), and texture (83%, χ^2=34.2, df=2, p<0.05) (Figure 6A). Regardless of the evaluation that consumers gave to texture, the flesh characteristic was mentioned as ideal for shredded or sliced fish recipes.

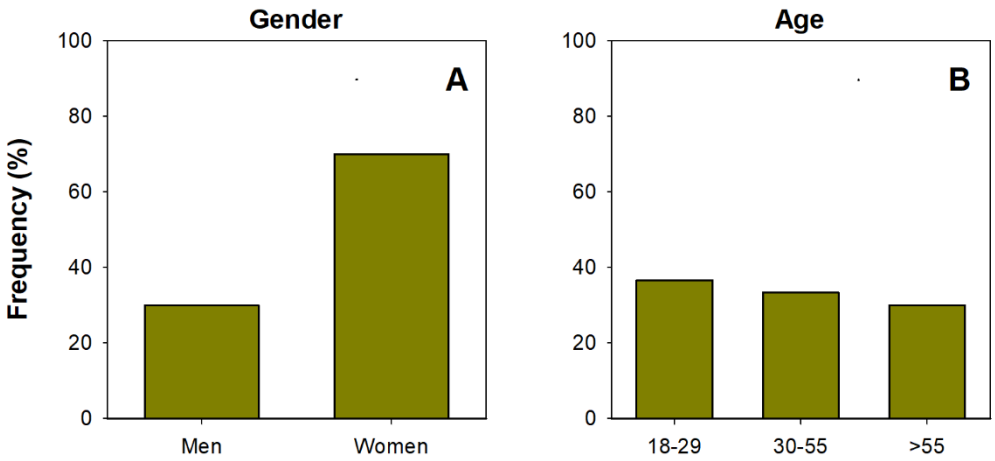


Figure 5. Gender (A) and age-distribution (B) of the consumers that replied to the Weakfish Survey.

The top cooking methods were roasting (27.3%), boiling (25.0%), and grilling (25.0%), and lastly, the other ways of preparation were Portuguese fish stew (*caldeirada*) and fish pasta (*massada de peixe*) (Figure 6B). Please note, that six consumers prepared the fish in three different ways – grilled, roasted, and stewed (*caldeirada*). Weakfish was never ranked as the favorite fish and most consumers ranked weakish in the fifth position (37%) (Figure 6C). After computing the average rank for each of the seven species, weakfish ranked in the sixth position: sardine- 2.8, gilthead seabream- 2.9, meagre- 3.5, mackerel- 3.9, salmon- 4.1, weakfish- 5.1, flounder- 5.7. Most consumers would buy weakfish if available at the market (90%, χ^2= 64, df= 1, p-value< 0.05). They would be willing to pay 8.3 ± 6.2 € kg^{-1}, which is significantly less than what they consider to be a fair price (9.5 ± 6.4 € kg^{-1}, t= 13.5, p< 0.05) (Figure 6D).

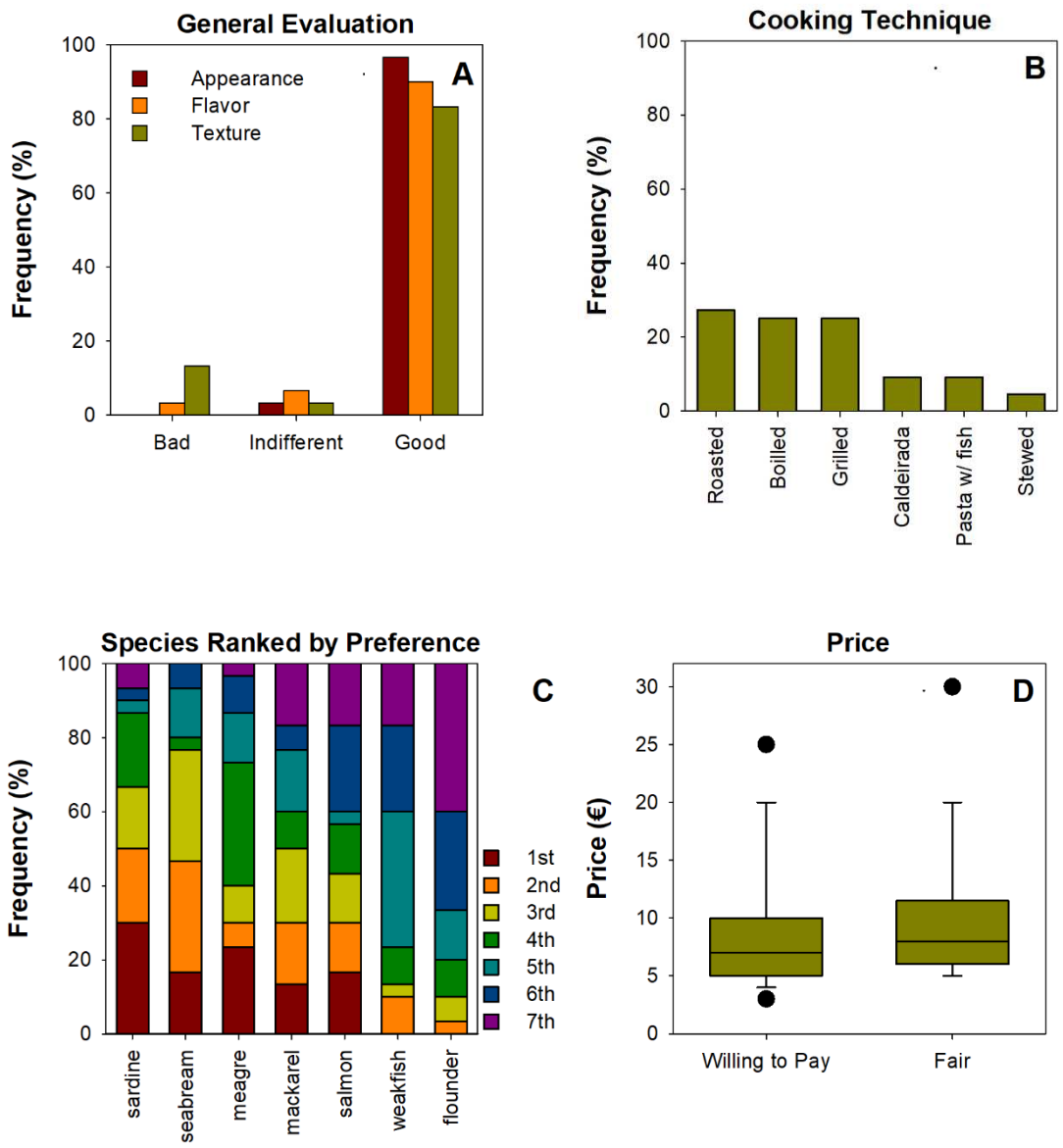
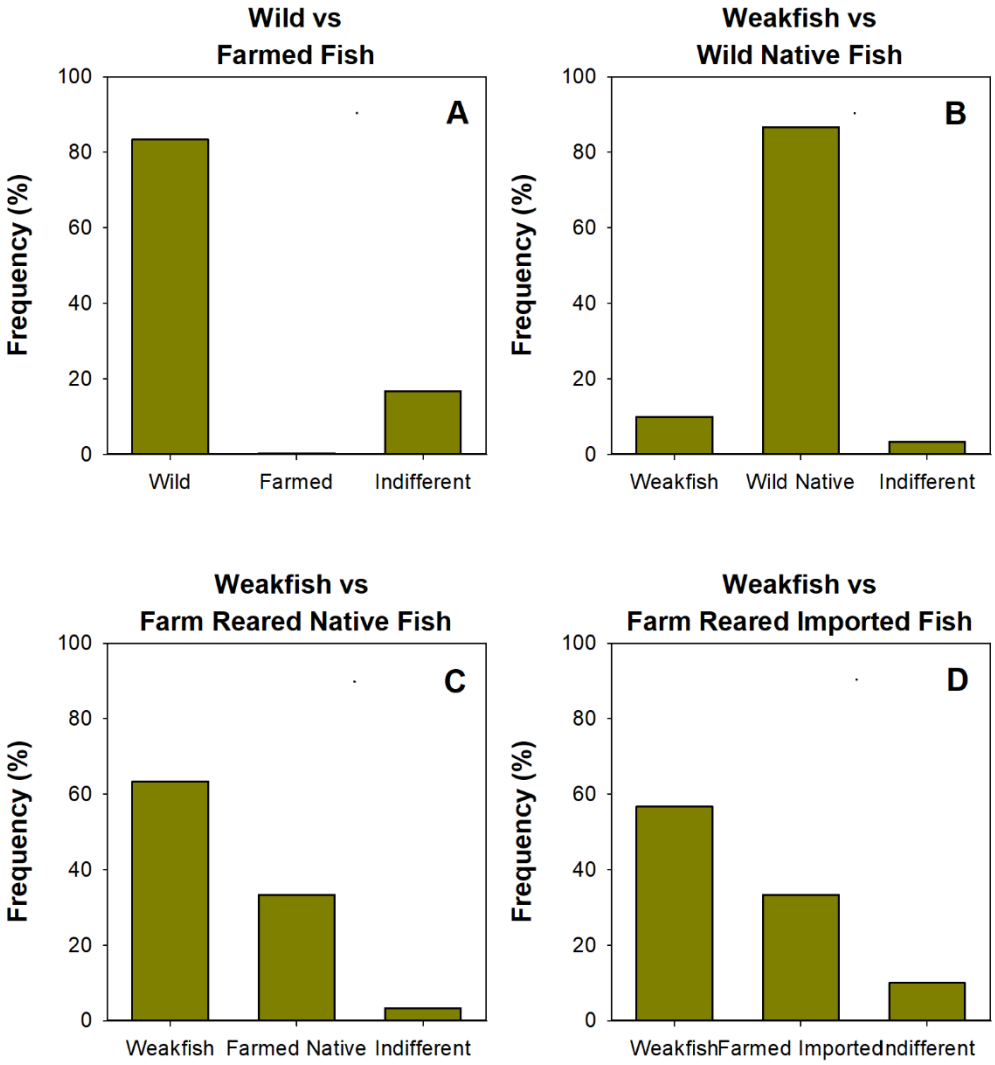


Figure 6. (A) Evaluation of weakfish's appearance, flavor, and texture by a panel of consumers. (B) Cooking methods chosen by consumers to cook weakfish at their homes. (C) Preference ranking of seven fish species – European pilchard *Sardina pilchardus (Walbaum, 1792)*, gilt-head seabream *Sparus aurata* Linnaeus, 1758, meagre *Argyrosomus regius* Asso, 1801, Atlantic horse mackerel *Trachurus trachurus* (Linnaeus, 1758), Atlantic salmon *Salmo salar* Linnaeus, 1758, weakfish *Cynoscion regalis* (Bloch & Schneider, 1801), and European flounder *Platichthys flesus* (Linnaeus, 1758). (D) Comparison between the average price consumers are willing to pay for weakfish and the price that they consider to be the fair price.

253 Consumers significantly prefer wild fish (83%) over farmed fish (0%) (χ^2= 35, df=
254 2, p-value< 0.05), while 17% had no preference (Figure 7A). The majority would also
255 prefer buying wild native fish (87%) over weakfish (10%) (χ^2= 38.6, df= 2, p-value< 0.05)
256 (Figure 7B). However, they would prefer buying weakfish (63%) if the native fish
257 available at the market would be farmed fish (33%) (χ^2= 16.2, df= 2, p-value< 0.05)
258 (Figure 7C). Consumers also prefer buying weakfish (57%) over imported farm-reared
259 fish (33%) (χ^2= 9.8, df= 2, p-value< 0.05) (Figure 7D).



260

261 Figure 7. Consumers' preference between wild and farmed fish (A), weakfish and wild
262 native fish (B), weakfish and farm-reared native fish (C), and weakfish and farm-reared
263 imported fish (D).

3.2. Measuring outreach impact

The two press releases resulted in thirty-eight online articles, and three news pieces broadcasted on national television. The online articles were published in Portuguese and two months, between September 28 and November 28, 2017. Twenty-two news pieces mentioned weakfish, while sixteen mentioned the Atlantic blue crab. Of the twenty-two items referring to weakfish, fourteen were published in online news websites, that include some of the leading Portuguese daily (*Público, Diário de Notícias, Correio da Manhã*) and weekly newspapers (Expresso), TV networks websites (*RTP, SIC Notícias, Porto Canal*), and local newspapers (e.g., *Diário Online Região Sul, Jornal do Algarve*) (Figure 8). Eight online publications were made in blogs. All references are listed as a supplement (Supplementary Table 1).

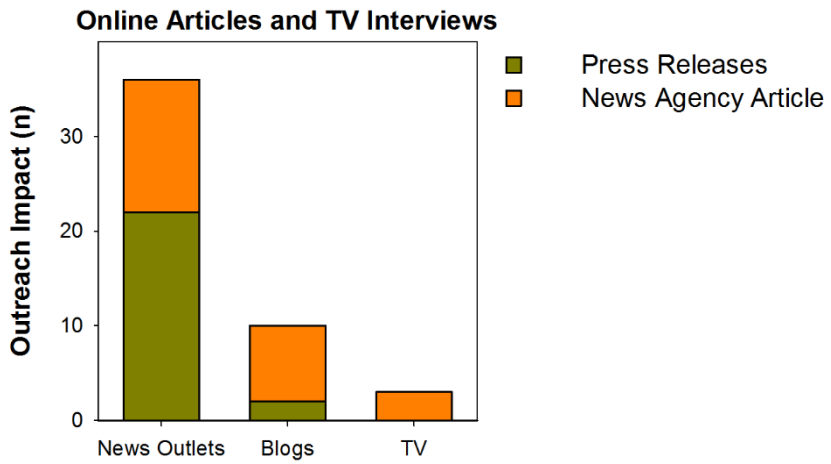


Figure 8. Number of news published and broadcasted mentioning weakfish as an invasive species in Portugal, as a consequence of the press releases made by the communication department of CCMAR in September 2017, and the article published by the news agency LUSA on December 30, 2017.

Regarding the TV broadcasts, two national TV channels reported the presence of weakfish and other invasive species in Portuguese estuaries. This coverage resulted in three appearances on TV with a total duration of 19’57”. The first news piece was transmitted by *TVI* in *Jornal das 8* newscast on October 8th, 2017, which lasted for 2’17’’ (TVI 2017) (Figure 9A). In the following days, *RTP 1* broadcasted two interviews featuring three researchers involved in this project and a fisherman from the Guadiana estuary that collaborates with our research group since 1999. The first interview was aired on October 9th, 2017, in the show *Portugal em Direto*, and lasted 14’15’’ (RTP1 2017a) (Figure 9B). A shorter version, with 2’40”, was broadcasted on October 30th, 2017, during the evening’s newscast on *Telejornal* (RTP1 2017b).

Figure 9. Interviews given to *Jornal das 8* (TVI) (A) and *Portugal em Direto* (RTP 1) (B) aired on October 8, 2017, and October 9, 2017, respectively.

The interview published in the Portuguese news agency LUSA featuring the research team and Chef Leonel Pereira resulted in twenty-four news published between December 30, 2017, and February 2, 2018. Twenty-four news pieces were published on news websites including some of the most relevant online newspapers in Portugal (e.g., Expresso, Jornal de Notícias, Destak, Observador, O Jogo), local newspapers (e.g., A Voz

do Algarve, Jornal da Madeira), and two in the websites of private businesses (O Instalador 2018, Somanjar 2018) (Supplementary Table 2).

4. Discussion

The Weakfish Survey showed that weakfish has the potential to be accepted by Portuguese consumers. Therefore, there is a base to promote a targeted fishery upon this species which could minimize the impacts of this invasive species while providing additional revenue to local fishers and fish vendors. Overall, the evaluation of weakfish's characteristics was good, and most consumers would buy this species if available at the market. The outreach regional events highlighted in the press releases allowed us to reach a national audience due to successful media coverage. We also provide an overview discussion about the benefits and risks of creating a management plan focusing on promoting weakfish as a fishery to mitigate the species ecological impacts and diversify the sources of income for local fishers and fish vendors.

4.1. The Weakfish Survey

The Weakfish Survey provided useful insights into the acceptability of weakfish by Portuguese consumers. The weakfish appearance, flavor, and flesh texture were the most appreciated traits, and most consumers (90%) would buy weakfish during a future visit to the market. Consumers advised that the flesh texture is ideal for shredded or sliced fish recipes, which are techniques used in several Portuguese fish recipes (Modesto 1983). So, linking weakfish with traditional recipes is important while promoting the species to consumers.

Consumers also found a good value in weakfish because they were willing to pay at least 60% more (i.e., 8 € kg^{-1}) than the mean price of 5 € kg^{-1} in 2017. This supports our hypothesis that weakfish's average selling price was underestimated. This also means that local fishers and fish vendors can obtain additional income from this fishery.

Consumers indicated that they prefer wild fish – including weakfish – instead of farmed species if sold for the same price. Although this preference could be related to sociodemographic aspects (e.g., age, education, income) (Myrland *et al.* 2000; Cardoso *et al.* 2013), our panel was composed of a diverse sociodemographic group. So, this generalized opinion was unexpected since older consumers are the ones that tend to disproportionally prefer wild fish over farmed fish (Cardoso *et al.* 2013). However, this trend could hypothetically be noticed if a larger set of consumers would have been surveyed. So, promoting weakfish as a wild species is of the utmost importance if environmental agencies decide to promote a fishery on weakfish as a means to control this invasive species.

Although the overall opinion on weakfish traits was good and consensual, it must be mentioned that is highly unlikely that weakfish will ever become the Portuguese's favorite fish species, despite that all weakfish sold in Portugal are wild fish (Morais *et al*. 2017). This is supported by the position that consumers ranked weakfish, sixth among seven wild fish species – only ahead of flounder, and far behind sardine – an economic and culturally important species for the Portuguese (Chícharo *et al.* 1998). Consumers justified their choices with personal preferences and consumption habits.

Overall, the invasive weakfish has an intrinsic marketing advantage over farmed fish besides the selling price. These are two features that should be considered when

promoting a fishery on weakfish as a means to control its population and minimize its impacts upon native species.

4. 2. Outreach – act locally, think nationally

The Weakfish Survey and outreach events that we promoted indicated that Portuguese consumers are likely to include weakfish in their shopping list. The outreach events also served to grab the media's attention to the ecology of invasive species, describe their impacts, and promote their use as new food delicacies as a means to minimize their impacts upon native species and increase the revenue of local fishers.

The media's interest in invasive species exceeded our expectations, both in number and time during which news and interviews were published and broadcasted. Although it is impossible to indicate the number of people who read the online news pieces and watched the broadcasted interviews, we estimate that they have reached many thousands of people in Portugal and abroad. All media contents are available online and were posted by some of the most important news outlets in Portugal (Supplementary tables 1 and 2).

An "act locally and think nationally" strategy drew attention to a local problem – the invasion of weakfish in southern Portugal – while raising awareness to the broader problem of invasive species, either aquatic or terrestrial, across a broader geographical scale. This overall strategy can be replicated for other edible invasive species anywhere in the world, although tailored adaptations to local contexts are recommended.

371 **4.3. Commercial fishery to control invasive species**

372 Long-term harvesting programs aiming to control and reduce the population size
373 of aquatic invasive species have been successfully implemented (Hauton *et al.* 2007;
374 Holbrook *et al.* 2016; Závorka *et al.* 2018), especially in confined areas (Weidel *et al.*
375 2007; Wittmann *et al.* 2012). This has been the case of a management plan on invasive
376 rusty crayfish *Orconectes rusticus* (Girard, 1852) in the Sparkling Lake (Wisconsin, United
377 States) where the population size decreased 99% in 8 years (2001-2008) and did not
378 increase significantly in the first four years postharvest (Hansen *et al.* 2013). Another
379 successful case-study was the control of the Asian carp in the Mississippi and Ohio River
380 basins (ACRCC 2016). Control plans focused on prevention, detection, fishery
381 management, control, and outreach (ACRCC 2016, www.AsianCarp.us). During three
382 years, the population size decreased through commercial harvest which then remained
383 at lower levels (Love *et al.* 2018). However, there are also cases where the population
384 size may rebound once removal rates decrease, as predicted for the invasive populations
385 of red lionfish *Pterois volitans* (Linnaeus, 1758) and common lionfish *Pterois miles*
386 (Bennett, 1828) (Barbour *et al*. 2011).

387 Although there is an information-deficit about weakfish ecology in the invasive
388 range, the eradication of aquatic organisms has proven to be difficult when invasive
389 species are not confined to small and enclosed areas (Simberloff 2014). So, we recognize
390 that the eradication of weakfish is extremely difficult given its broad distribution in the
391 Iberian Peninsula (Morais *et al.* 2017). However, we do recommend harvesting programs
392 targeting weakfish in the most invaded areas, like in the Sado estuary. Such a control
393 program would aim at i) minimizing ecological impacts and ii) increasing the income of
394 local fishers and fish vendors.

Controlling the weakfish population through harvest would reduce predation pressure upon native species and chances of introduction to surrounding areas. Involving motivated local knowledge experts (fishers and anglers) and citizen scientists would increase the success of a long-term control plan while raising their awareness of biological invasions (Encarnação *et al.* 2021). However, adopting any population control program also entails several risks, as not being able to remove enough individuals to decrease the population density (Pasko *et al.* 2014), harming native species through by-catch (Pasko *et al.* 2014), and other unexpected ecological consequences by altering the food web structure (e.g., biological overcompensation, opening ecological niches for other species) (Zavaleta *et al*. 2001, Zipkin *et al.* 2009). Therefore, any population control plan for weakfish – or any other invasive species – must be done after assessing its ecology in the invaded range and interaction with native species, as well as determining which life stages are more likely to be affected by harvest.

In terms of economic benefits, we showed that weakfish has the intrinsic qualities that are appreciated by Portuguese fish consumers. It is easy to harvest and it can be sold away from the region of capture without the risk of introduction into other areas. So, the implementation of an adequate marketing strategy and scientific-based control program could make weakfish fisheries a paradigmatic example of how to transform an ecological threat into an economic opportunity for local fishers and fish vendors while providing a healthy source of marine protein. However, we must not forget that creating a profitable fishery may discourage the eradication of the target species (Nuñez *et al.* 2012), particularly if it becomes overpriced in comparison to native species since it may lead to its protection in detriment of natives (Lambertucci and Speziale 2011). So, all stakeholders should be informed about the negative effects of

invasive species, that introducing non-indigenous species is illegal, and that the economic benefits that invasive species may generate are smaller than the long-term costs associated with a program that controls the population of an invasive species and the impacts on native species and ecosystems (Lambertucci and Speziale 2011, Varble and Secchi 2013). In other words, the purpose of the management plan is not the perpetuation of a viable fishery but rather the substantial decrease of an invasive species population (Nuñez *et al.* 2012). Simultaneously, outreach campaigns focusing on the conservation of native fisheries should be encouraged, as well as the commercialization of native species that are not being valued to shift the focus from perpetuating the fishery of an invasive species and introducing it somewhere else.

Conclusion

Our intrinsic knowledge about Portuguese consumers' preferences regarding fish confirmed the three main hypotheses of this work. Weakfish has the potential to become a targetted fishery in Portugal and represent an additional source of income for local fishers and fish vendors. The mean selling price of weakfish was underestimated by fish vendors because consumers were willing to pay 3 € kg^{-1} above the average selling price of 5 € kg^{-1}. Consumers also recognized that one of the main attributes of weakfish is being a wild species, which must be highlighted when promoting the species to consumers. The interest shown by the media and the curiosity of culinary Chefs about edible invasive species demonstrates that invasive species can be turned into an economic opportunity and their impacts minimized if science-driven fisheries are to be put into practice.

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Contributions

MAT and PM conceived the research questions and study design. IC and VB conducted the surveys. IC, VB, and MAT conducted the outreach actions. IC and PM analyzed the data. IC wrote the initial draft of the paper and PM, MAT, and VB provided substantial feedback on this initial version. All authors gave final approval for publication.

Data availability

The raw data presented in this work can be made available upon request.

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Supplementary Table 1. List of twenty-two news pieces published online, between September 28 and October 21, 2017, after the two press releases made on September 2017 by CCMAR (2017a,b). These articles are listed chronologically.

Correio da Manhã

September 28, 2017
Link

Diário de Notícias

September 28, 2017
Link

Diário Online Região Sul

September 28, 2017
Link

O Jogo

September 28, 2017
Link

País ao Minuto

September 28, 2017
Link

Portugal Notícias

September 28, 2017
Link

Público

September 28, 2017
Link

RTP Notícias

September 28, 2017
Link

SIC Noticias

September 28, 2017
Link

Sul Informação

September 28, 2017
Link

Tempo no Algarve

September 28, 2017
Link

TVI 24

September 28, 2017
Link

Ultimate Science

September 28, 2017
Link

A Roda

September 29, 2017
Link

Diário de Notícias

September 29, 2017
Link

Net Madeira

September 29, 2017

Link

Últimas Curiosidades

September 29, 2017

Link

Ambiente Ondas3

September 30, 2017

Link

Hélder Barros

September 30, 2017

Link

Cidadania

September 30, 2017

Link

Jornal do Algarve

October 8, 2017

Link

Portal do Mar

October 21, 2017

Link

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Supplementary Table 2. List of twenty-four news pieces published online, between December 30, 2017, and February 2, 2018, after the article published by LUSA on December 30, 2017 (LUSA 2017). These articles are listed chronologically.

Destak

December 30, 2017

Link

Diário de Notícias

December 30, 2017

Link

Expresso

December 30, 2017

Link

Impala News

December 30, 2017

Link

JM Madeira

December 30, 2017

Link

Jornal de Notícias

December 30, 2017

Link

O Jogo

December 30, 2017

Link

Observador

December 30, 2017

Link

Porto Canal

December 30, 2017

Link

RTP Notícias

December 30, 2017

Link

Sapo 24

December 30, 2017

Link

TSF Rádio Notícias

December 30, 2017

Link

A Voz do Algarve

January 1, 2018

Link

Antena 1

January 1, 2018

Link

Diário de Notícias

January 1, 2018

Link

Impala News

January 1, 2018

Link

LUSA

January 1, 2018

Link

Observador

January 1, 2018

Link

O Jogo

January 1, 2018

Link

RTP Notícias

January 1, 2018

Link

Somanjar

January 1, 2018

Link

Diário Campanário

January 2, 2018

Link

Folha do Domingo

January 3, 2018

Link

O Instalador

February 2, 2018

Link

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Figures

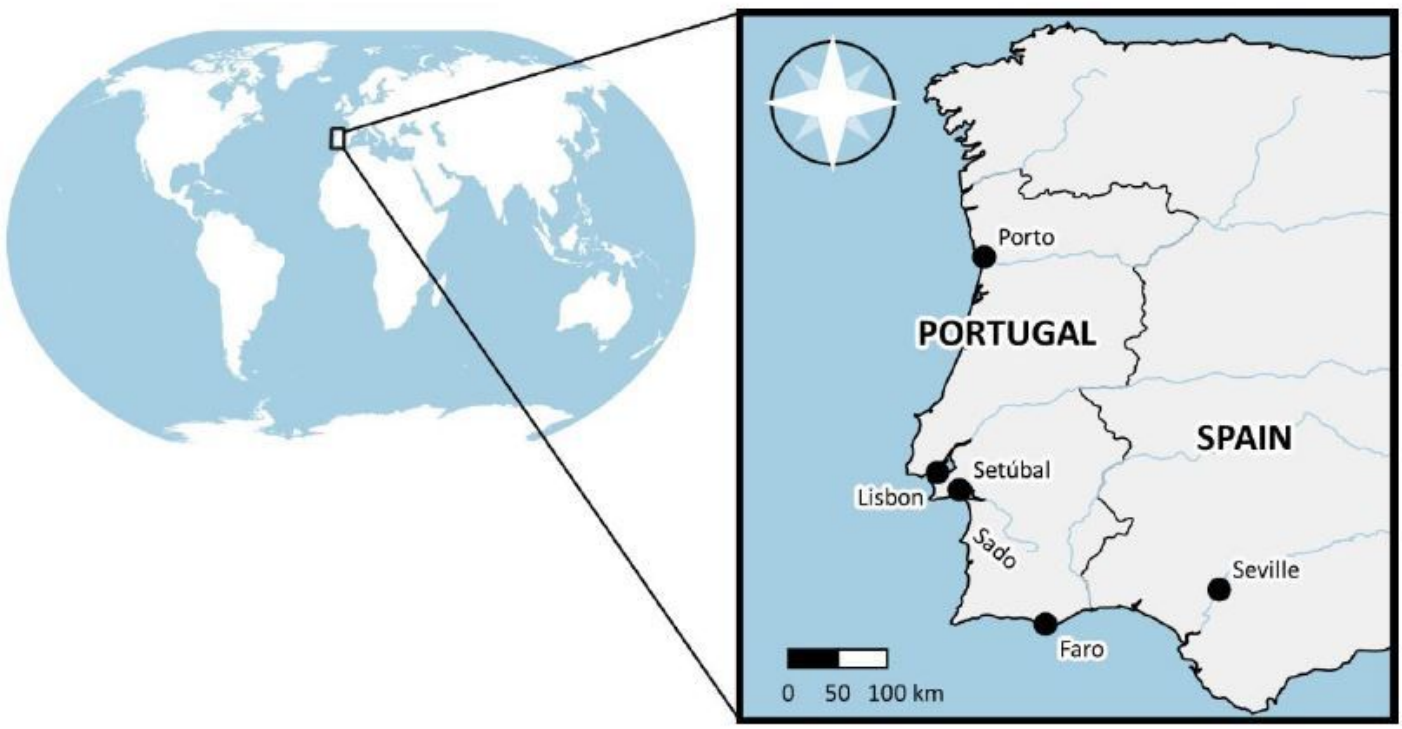

Figure 1

Location of Setúbal (Portugal) and the Sado estuary in Portugal (Europe). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

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THE WEAKFISH SURVEY

This survey is being conducted by Inês Cerveira, as part of her Master Thesis in Marine Biology at the University of Algarve. The thesis' title is "Weakfish *Cynoscion regalis* (Pisces: Sciaenidae) (Bloch & Schneider, 1801) ecology in its non-indigenous range and its potential as a new fishing resource" and the advisors are Dr. Pedro Morais and Professor Maria Alexandra Teodósio.

Name _____ Age _____ Contact _____

Question 1 Please provide a general assessment about weakfish's appearance, flavour, and flesh texture.

	Bad	Indifferent	Good
Appearance	☐	☐	☐
Flavour	☐	☐	☐
Texture	☐	☐	☐

Question 2 Please mention which cooking technique you used to cook weakfish.
Boiled ☐ Grilled ☐ Roasted ☐ Fried ☐ Other ☐

Question 3 Would you buy weakfish from the market? Yes ☐ No ☐

Question 4 How much would you pay for weakfish? _____

Question 5 What would be a fair price to pay for a wild fish as weakfish? _____

Question 6 Do you prefer wild weakfish ☐ or other wild fish as gilthead seabream ☐, seabass ☐, or meagre ☐?

Question 7 Do you prefer wild weakfish ☐ or other fish produced in aquaculture as gilthead seabream ☐, seabass ☐, or meagre ☐?

Question 8 For the same price, would you rather buy wild weakfish or other fish produced in aquaculture as gilthead seabream ☐, seabass ☐, or meagre ☐?

Question 9 Order the following fish from 1 (favorite) to 7 (least favorite) according to your culinary preferences.
flounder ☐ gilthead seabream ☐ horse mackerel ☐
meagre ☐ salmon ☐ sardine ☐ weakfish ☐

Question 10 Do you prefer wild fish ☐ or aquaculture fish ☐?

Thank you for your collaboration!

Figure 2

The Weakfish Survey was delivered to a panel of 30 Portuguese consumers to evaluate their opinion on weakfish Cynoscion regalis (Bloch & Schneider, 1801), as well as their preference between weakfish versus several wild and aquacultured fish.

Figure 3

Tasting session at Algarve Mental Health Association (ASMAL) canteen. Chef Avelino Falé and his staff (ASMAL's students) (left) who prepared the weakfish served at ASMAL – roasted weakfish and potatoes with red bell peppers (right).

Figure 4

Image posted by Chef Leonel Pereira on Instagram about his experiments with weakfish at his experimental kitchen in the São Gabriel restaurant (Creative Cook Garage 2018).

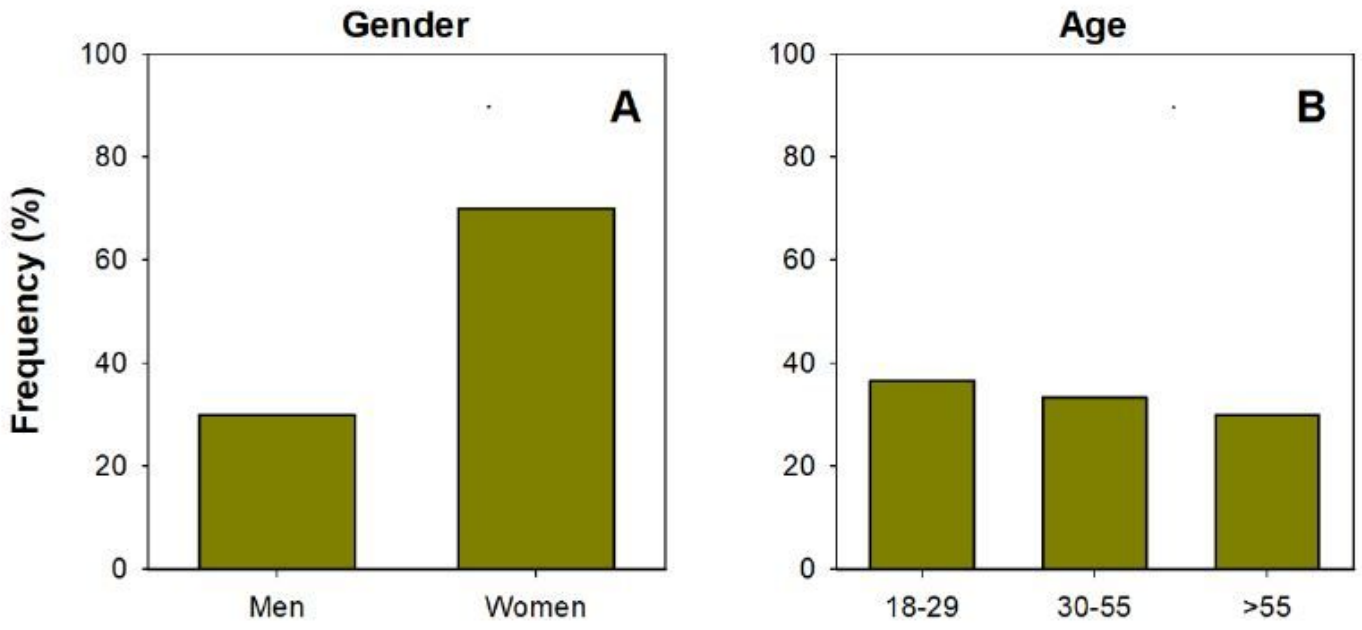

Figure 5

Gender (A) and age-distribution (B) of the consumers that replied to the Weakfish Survey.

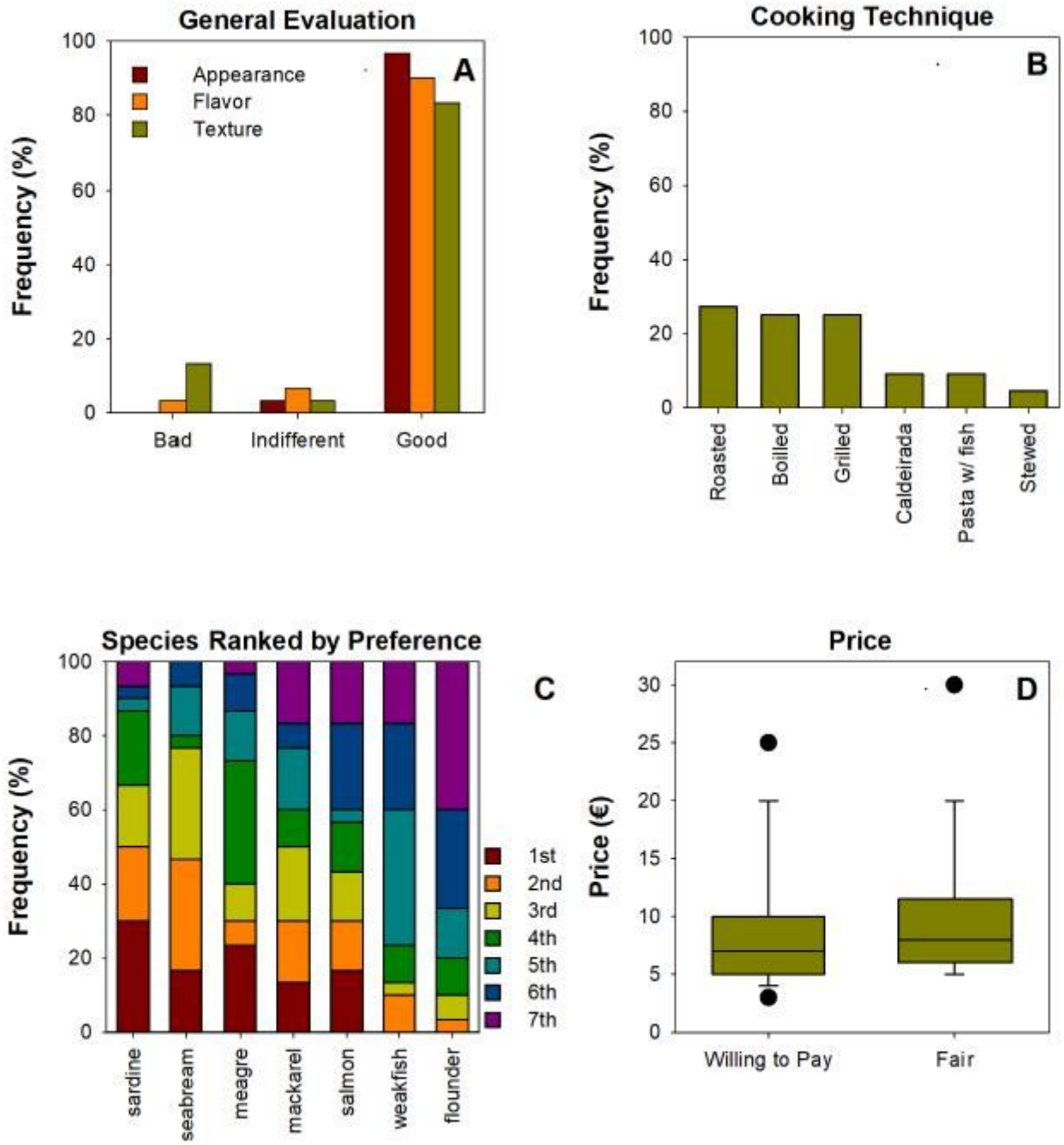

Figure 6

(A) Evaluation of weakfish's appearance, flavor, and texture by a panel of consumers. (B) Cooking methods chosen by consumers to cook weakfish at their homes. (C) Preference ranking of seven fish species – European pilchard Sardina pilchardus (Walbaum, 1792), gilt-head seabream Sparus aurata Linnaeus, 1758, meagre Argyrosomus regius Asso, 1801, Atlantic horse mackerel Trachurus trachurus (Linnaeus, 1758), Atlantic salmon Salmo salar Linnaeus, 1758, weakfish Cynoscion regalis (Bloch & Schneider, 1801), and European flounder Platichthys flesus (Linnaeus, 1758). (D) Comparison between the average price consumers are willing to pay for weakfish and the price that they consider to be the fair price.

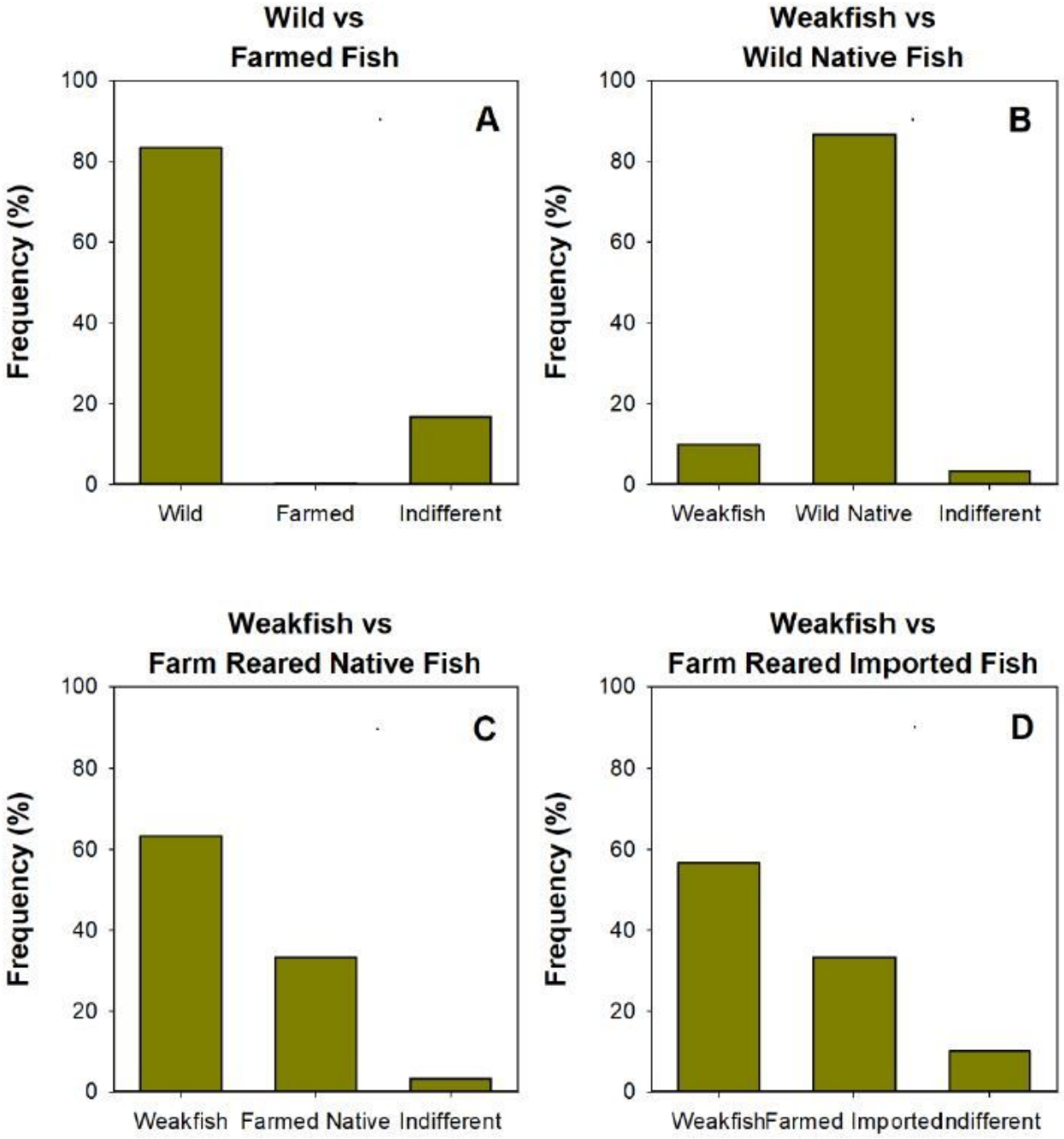

Figure 7

Consumers' preference between wild and farmed fish (A), weakfish and wild native fish (B), weakfish and farm-reared native fish (C), and weakfish and farm-reared imported fish (D).

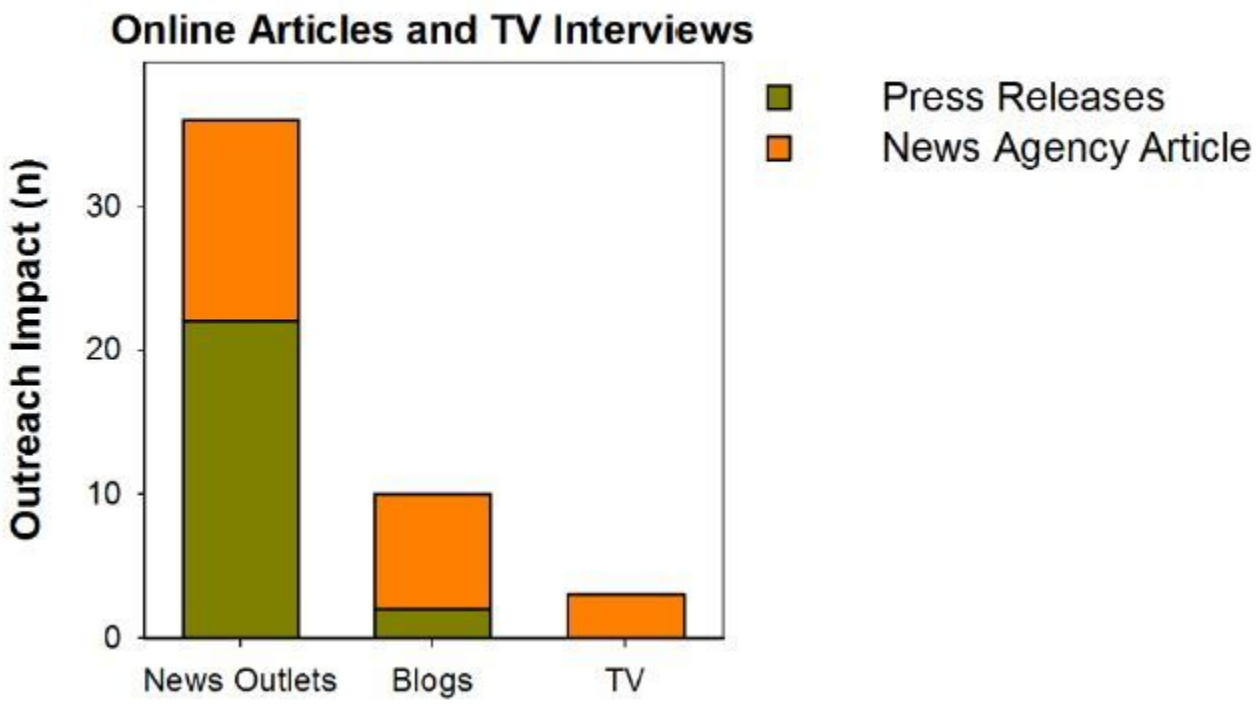

Figure 8

Number of news published and broadcasted mentioning weakfish as an invasive species in Portugal, as a consequence of the press releases made by the communication department of CCMAR in September 2017, and the article published by the news agency LUSA on December 30, 2017.

Figure 9

Interviews given to Jornal das 8 (TVI) (A) and Portugal em Direto (RTP 1) (B) aired on October 8, 2017, and October 9, 2017, respectively.