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Rapid Communication

Evaluating the range expansion of recreational non-native fishes in Portuguese freshwaters using scientific and citizen science data

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Abstract

Updating information on the distribution of recently introduced and other poorly known non-natives is essential to prevent and control their spread and better address biological invasions. Here, we combine scientific and citizen science data to update the distribution of five recently arrived (i.e., < 25 years), non-native fish species (*Alburnus alburnus*, *Ameiurus melas, Rutilus rutilus*, *Sander lucioperca* and *Silurus glanis*) and one rare, longer established (i.e., > 50 years), non-native (*Esox lucius*) in Portugal. These species have been increasingly targeted by recreational fishermen, thus likely expanding their distribution. Specifically, we obtained distribution maps for each species, based on data gathered through a comprehensive search for records in 1) scientific literature, 2) unpublished reports of research projects, and 3) citizen science databases. We gathered 443 valid records, of which 64% were from citizen science data, mainly provided by recreational fishermen. Data highlighted that all species have expanded their distribution in the last 20 years, with high numbers of new records for *A. alburnus, S. lucioperca* and *S. glanis*, mostly located in the Tagus, Guadiana and Douro river basins. Changes in species distributions reflected dispersal within invaded basins and colonisation of previously unoccupied drainages. Integrating citizen science with scientific data provides an effective framework to understand non-native species introduction and spread, stressing the need for increasingly encourage and engage recreational fishermen in information sharing.

Key words: invasive fish, spread, spatial distribution, fishermen, invasion routes, Iberian Peninsula

Introduction

The Iberian Peninsula is a biodiversity hotspot for freshwater fishes, harbouring several endemic species, with very restricted distributions

(Smith and Darwall 2006; Freyhof et al. 2020). These species face significant declines and high extinction risk due to, among other threats, the introduction and proliferation of non-native fishes, which cause severe negative ecological, economic, and social impacts (Hermoso and Clavero 2011; Ribeiro and Leunda 2012; Maceda-Veiga 2013). In Portugal, the number of non-native fishes has increased significantly in the last decades, mainly due to the growing use of non-natives for sport fisheries and aquarium trade (Anastácio et al. 2019). In addition, the pace of establishment of new fish species may accelerate in the near future, at an approximate rate of one new non-native species every two years (Ribeiro et al. 2009a; Anastácio et al. 2019).

Most studies on freshwater fish invasions in Portugal focus on single species and river basins, over short periods of time, and do not provide accurate views of species spread and distribution expansion. Although the distribution of some long established (i.e., > 50 years) non-native fishes is relatively well known (e.g., Baduy et al. 2020), there is no updated information on the distribution of recently arrived (i.e., < 25 years) (but see Gago et al. 2016; Banha et al. 2017a), but also of rare, long established non-natives. Knowledge of species distribution is crucial for effective monitoring plans of non-native fishes and future implementation of management actions that effectively prevent and control their spread (Caffrey et al. 2014).

A growing number of options has become available as sources of data for studying the distribution of fishes. Scientific and citizen science data have increasingly been combined in such studies (Martelo et al. 2008; Venturelli et al. 2016; Støttrup et al. 2018), mainly because this strategy allows the collection of data over large spatial and temporal scales, which may otherwise be logistically and financially inaccessible (Dickinson et al. 2010). In the Iberian Peninsula, citizen science has provided valuable information about the introduction and spread of two species of catfish (Gago et al. 2016; Banha et al. 2017a).

Here, we combine scientific and citizen science data to assess the distribution of five recently arrived non-native freshwater fish species: bleak *Alburnus alburnus* (Linnaeus, 1758), black bullhead *Ameiurus melas* (Rafinesque, 1820), roach *Rutilus rutilus* (Linnaeus, 1758), pikeperch *Sander lucioperca* (Linnaeus, 1758) and European catfish *Silurus glanis* Linnaeus, 1758, and one long established non-native: northern pike *Esox lucius* Linnaeus, 1758. These species are highly valued by recreational fishermen in Portugal, thus representing a high risk of introduction and spread (e.g., Ribeiro et al. 2009b; Gago et al. 2016; Banha et al. 2017b).

Materials and methods

We performed a comprehensive search for occurrence records of non-native fishes in Portugal, using different sources of information: 1) data

from scientific literature (journals, academic theses and technical reports), 2) unpublished data from research projects, and 3) citizen science data. We started by gathering data from the literature on first occurrences of fishes in river basins in Portugal. To achieve this, we conducted a Boolean search on Google Scholar, using the species common names in Portuguese and scientific names, the words "Portugal" and "Portuguese" as key words, and "AND" and "OR" as operators, with unlimited search date. We then compiled records using fish capture data collected in the frame of different research projects. Research projects were conducted in 2009–2019, covered the main river basins in Portugal (i.e., Lima, Ave, Cávado, Douro, Vouga, Mondego, Tagus, Sado, Mira and Guadiana), and provided capture data for all study species (see funding declaration for details). Although capture data were not yet published, data were available as all co-authors were directly involved in the projects. Finally, we gathered citizen science data by performing online searches for voluntary and responsive records obtained through direct requests, between January 2000 and May 2020. Online searches were mainly conducted on Facebook page of FRISK (FRISK 2020), a project targeting recreational fishermen engagement in non-native species record for reconstruction of invasive fish routes, and on BioDiversity4All (Biodiversity4All 2020), a Portuguese biodiversity citizen science platform connected to the international project iNaturalist. Other social media, including YouTube, recreational fishing forums and blogs, local newspapers, and TV and radio news were searched for additional fish data.

Citizen science data were assembled, checked, and validated only when associated with a picture or video that confirmed species identification (Gago et al. 2016). Although there could have been a bias due to the difference between the date in which the record was published online and the date of capture, we considered it to be minimal, as it may have affected only a reduced number of records given the time scale of our study (i.e., years). All fish life stages were considered as records, although citizen science data mainly referred to adult individuals. Geographical coordinates of each record were extracted from Google Earth Pro v.7.3.3 and mapped using QGIS 3.12.1.

Results and discussion

We compiled 443 valid records on individual occurrences for the six species, 21 from scientific literature, 137 from research projects and 285 from citizen science (Supplementary material Table S1). This resulted in 422 records not yet published, 44% in the Tagus, 20% in the Guadiana, 15% in the Douro and 21% in other river basins (Cávado, Sado, Ave, Mondego, Vouga and Mira, by decreasing order of records).

The different data sources provided variable amounts of records among basins and there was no overlap between records, that is, a record was not registered twice. About 40% of records from scientific literature were for

the Tagus and Guadiana river basins, 15% for the Ave and 5% for both the Douro and Sado. More than half of records from research projects, 61%, were for the Tagus River basin, 18 and 8% for the Guadiana and Douro, respectively, and 13% for other river basins (Vouga, Sado, Ave, Cávado and Mondego). Approximately 35% of records from citizen science were for the Tagus, 20% for the Guadiana and Douro, and the remaining 26% were distributed among other river basins (Cávado, Sado, Ave, Mondego, Vouga, Lima and Mira). The number of records was also variable among species. Bleak and pikeperch had the highest number of records, 36% and 30%, respectively, followed by European catfish and black bullhead, 12%, and next by roach and northern pike that had the lowest number of records, 5%.

European catfish, Silurus glanis

Knowledge of European catfish impact on Iberian aquatic communities is still limited, however, it likely represents a high risk to native fish species, which largely contribute to its diet (Ferreira et al. 2019). The species was first introduced in 2008, in the Tagus River, as indicated by citizen science records (Gago et al. 2016). Nevertheless, the first official record was in 2014, when local fishermen captured two individuals of 83 and 118 cm in the Tagus River (Gkenas et al. 2015).

We gathered 52 records of European catfish, of which 39 were from research projects and 13 from citizen science data. All records were in the Tagus River basin, except two in the Douro River, in 2019 and 2020 (Figure 1A). These are the first evidence of European catfish presence in the Portuguese section of the Douro River, which suggests a dispersal of approximately 70 km downstream from Spain (Parrondo et al. 2018). Given the increasing number of new introductions and range expansions of the species in the Iberian Peninsula, and the growing interest by recreational fishermen (Benejam et al. 2007; Moreno-Valcárcel et al. 2013; Gago et al. 2016), it is highly likely that other basins will be colonised in a near future. For example, the Guadiana River basin may be colonised by individuals from neighbouring drainages, such as the Guadalquivir River basin, where the species has recently been recorded (Sáez-Gómez and Prenda 2019), or from the Alqueva reservoir, which has been the recipient of several new non-native fishes (Ribeiro et al. 2006; Banha et al. 2017a).

Black bullhead, Ameiurus melas

Black bullhead has proved highly invasive and may be extremely detrimental to native fish communities through direct predation (Leunda et al. 2008). Its presence in Portugal was first confirmed in the Tagus River, in 2000, and one year later in the Guadiana River, near Mértola (Gante and Santos 2002). In 2003, the species was captured in the Alqueva reservoir, in the Guadiana River basin (Ribeiro et al. 2006). There were also reports of black bullhead in the Sado River basin (Gante and Santos 2002).

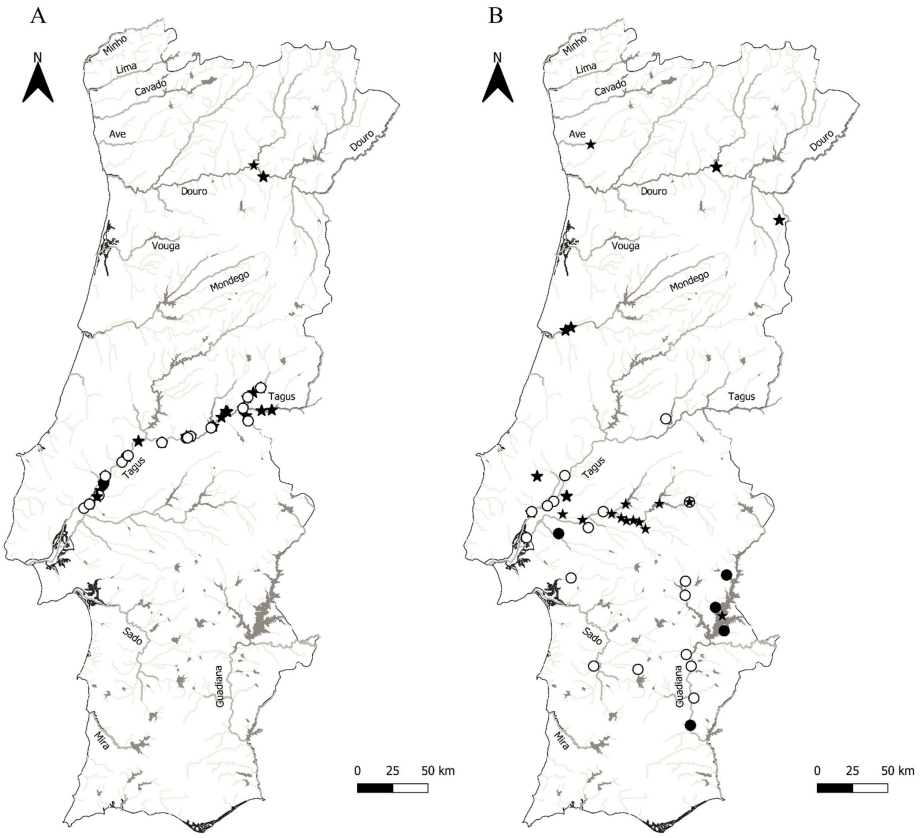

Figure 1. Distribution of *Silurus glanis* (A) and *Ameiurus melas* (B) in Portugal. Occurrences derived from records in scientific literature (journals, academic theses, and technical reports) (black circles), unpublished research projects (white circles) and citizen science data (black stars).

We collected 43 records of black bullhead, nearly half originating from citizen science (n = 26, Figure 1B). The species is widespread across Portugal, occurring in the main southern river basins (Tagus, Guadiana and Sado), but also in the North of the country (lower Mondego, Douro and Ave). While black bullhead likely arrived in Portugal due to natural spread of individuals from Spanish populations along the Tagus and Guadiana river basins (Gante and Santos 2002), translocations by recreational fishermen likely contribute to its presence in independent basins such as Mondego, Sado and Ave.

Bleak, Alburnus alburnus

The spread and successful establishment of bleak may have significant ecological impacts for native fishes, as it may hybridise with *Squalius alburnoides* (Steindachner, 1866), *Squalius pyrenaicus* (Günther, 1868), and possibly *Anaecypris hispanica* (Steindachner, 1866) (Almodóvar et al. 2012; Sousa-Santos et al. 2018). The first introduction of bleak in Portugal probably occurred in 1999, in a reservoir of the Caia River, a small tributary of the Guadiana River basin (Pérez-Bote et al. 2004). Its first official record was, however, only six years later, when Vinyoles et al. (2007) captured bleak in the same river. It has since spread rapidly, being subsequently detected in 2006 and 2007 in the Tagus and Sado river basins

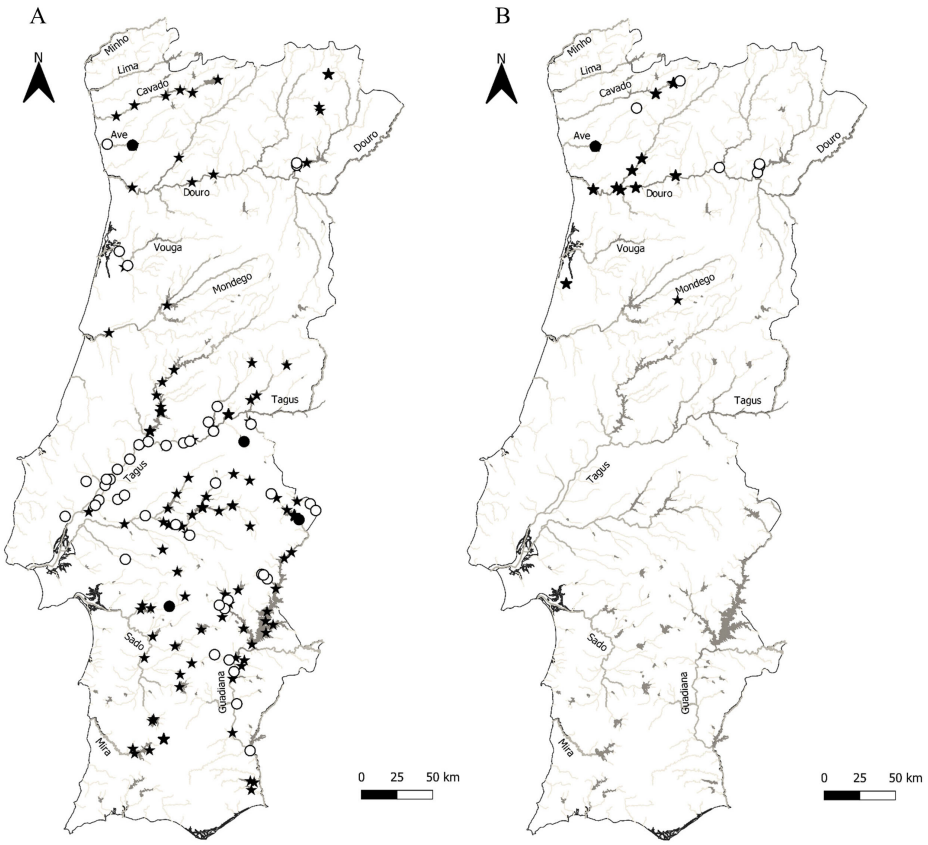

Figure 2. Distribution of *Alburnus alburnus* (A) and *Rutilus rutilus* (B) in Portugal. Occurrences derived from records in scientific literature (journals, academic theses, and technical reports) (black circles), unpublished research projects (white circles) and citizen science data (black stars).

(Oliveira 2006; Oliveira et al. 2007), and in 2012 in the Ave River, in the northwest of Portugal (Ribeiro and Veríssimo 2014).

We compiled 156 records, mainly from citizen science (n = 111), providing further evidence for the rapid and large expansion of the species across Portugal, notably in the Tagus and Guadiana river basins (Figure 2A). Furthermore, citizen science records provided the first evidence of bleak in the Mira, Mondego, Vouga, Douro and Cávado river basins, the last representing the northernmost occurrence of the species in Portugal to date. The introduction and range expansion of bleak have been associated with natural dispersal from the Spanish sections of the Guadiana, Tagus and Douro rivers, and with recreational fisheries (Vinyoles et al. 2007; Ribeiro et al. 2009a).

Roach, Rutilus rutilus

Little is known about the ecological impacts of roach, nevertheless, it is possible that it has a negative effect on the water quality of Iberian reservoirs (Ordóñez et al. 2010). Recreational fishermen reported the occurrence of roach in the Ave River since 2007, in online fish forums, but the scientific record of the species in north-western Portugal occurred only in 2012 (Ribeiro and Veríssimo 2014).

We gathered 23 records of roach, 17 from citizen science data and 6 from research projects. Roach has spread in the Ave River and has colonised two new basins, namely the Cávado and the Douro, being broadly distributed in the latter (Figure 2B). In addition, the species was reported by fishermen in isolated artificial lagoons (Lagoa de Calvão and Lagoa da Folhadosa), in the Vouga and Mondego river basins, respectively. Two introduction routes have been suggested for roach, either from Spanish basins where the species has been first introduced, or a direct introduction from France mediated by Portuguese emigrants (Ribeiro and Veríssimo 2014). Although the latter needs confirmation, it has been considered an important pathway for the introduction of other non-native fishes, such as *S. lucioperca* (Ribeiro et al. 2009b) and *Phoxinus* sp. (Garcia-Raventós et al. 2020).

Compared to other recently introduced non-native fishes, roach still occupies a relatively small area, and is probably at the start of its dispersal process. This may reflect the limited interest of roach for recreational fishermen, who have likely contributed to the rapid and wide spread of other non-natives, notably of bleak, which is highly appreciated for competition and as forage and bait fish. In addition, life history traits may play a role in limiting roach spread within river basins (Ribeiro et al. 2008).

Pikeperch, Sander lucioperca

As a top fish predator, preying on multiple native fish species, pikeperch may have negative consequences for native fish communities (Ribeiro et al. 2009b; Pérez-Bote and Roso 2012). The presence of pikeperch in Portugal was first reported for the Ave River (northwest of Portugal), in 1998 (Barros et al. 2000). One year later, the species was detected in the Douro River basin (Cortes et al. 2001), and subsequently has occurred southwards, in reservoirs of the Tagus and Guadiana river basins, in 2004 and 2005, respectively (Ribeiro et al. 2009b).

A total of 127 records of pikeperch, 100 obtained from citizen science and 28 from research projects were gathered, showing both new introductions and major expansions in previously invaded areas (Figure 3A). Five new basins, namely, Sado, Mondego, Vouga, Cávado and Lima have been colonised by pikeperch, and it has spread downstream along the Ave, Tagus, and Guadiana river basins.

Northern pike, Esox lucius

Northern pike is a predatory fish that might have a detrimental impact on native fish communities (Dominguez and Pena 2000), but it has been mostly restricted to reservoirs. The species was recorded for the first time in the main Guadiana River, in 1962 (Almaça 1965). In 1995, northern pike was collected in the Xévora River, indicating that it either has spread northwards across the Guadiana River basin or dispersed downstream from Spain (Pires et al. 1999). In the same year, the species was reported in the Tagus River

Figure 3. Distribution of *Sander lucioperca* (A) and *Esox lucius* (B) in Portugal. Occurrences derived from records in scientific literature (journals, academic theses, and technical reports) (black circles), unpublished research projects (white circles) and citizen science data (black stars).

basin (Almaça 1995). In 2012, the species was recorded in the Sabor reservoir (Miranda 2012), however, its presence in the Douro River basin was noted earlier, probably due to the downstream dispersal of individuals from Spain, where the species was stocked in the late 1950s in the Esla River, close to Portugal (Pena 1986; Dominguez and Pena 2000).

We gathered 21 records, primarily from citizen science (n = 18), indicating that the species occurs mainly in the Douro, but also in the Guadiana and Tagus river basins (Figure 3B). Records indicated the species has been captured exclusively in large reservoirs (e.g., Sabor, Azibo, Cedillo and Alqueva), except in the lower Tagus basin, where captures also occurred in the mainstem.

Final remarks and future prospects

We provide the most comprehensive distribution data of six non-native fishes in Portugal, by complementing research data with online recreational fishermen records. We observed that all species expanded their distribution in the last 20 years, likely through dispersal across invaded basins and human-assisted introductions into new drainages and reservoirs. All species, except roach and pikeperch, were first recorded in international southern river basins (Tagus and Guadiana), subsequently

occurring in nearby rivers, and later expanded northwards, mostly in reservoirs. Conversely, roach occurred first in northwest Portugal (Ave River basin), being further detected in neighbouring drainages, and then spreading southwards. Pikeperch was first detected in both southern and northern river basins, expanding its range afterwards across the country. Furthermore, we demonstrated that multiple sources of data can be used to inform on the range expansion of non-natives fishes in Portugal, adding support for the importance of complementing scientific records with citizen science data to improve the spatial and temporal scope of non-native species distribution studies, and provide insights for management and research needs.

Despite all fishes being highly recreationally valued in Portugal, our records were likely species- and spatially biased. In particular, records from citizen science were dependent on species' popularity among recreational fishermen (i.e., trophy *versus* bait species) and/or preference for particular fishing locations (Marta et al. 2001). Indeed, 66% of records were obtained in reservoirs and artificial lagoons, as found by Gago et al. (2016). Furthermore, citizens' motivation to provide information may have been conditioned by unlawful behaviours and/or conflicts with management agencies, therefore, species such as *E. lucius* or *S. lucioperca*, may have larger distribution ranges than those presented here. Nevertheless, and despite the identified biases, our study may help designing effective monitoring and management plans for the study species, which are crucial to ameliorate their effects on native species. Notably, management actions to control or limit the dispersal of top predators such as *S. glanis* and *S. lucioperca* are urgently needed.

Future actions (e.g., outreach programmes and dissemination activities) should be encouraged, and aim at increasing citizen scientists' engagement in sharing information, particularly of recreational fishermen, while simultaneously increasing awareness for the problem of introducing non-native fishes. These actions have proved highly efficient for enhancing fishermen recording of popular non-natives (e.g., FRISK and LIVE INVASAQUA projects). Furthermore, efforts to promote the engagement between fishermen and management institutions should also be supported to improve knowledge on the effectiveness of policies, and to promote practices (e.g., early warnings) that may limit further introductions and spread of non-native fishes.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Location of records for non-native fish species in Portuguese river basins, derived from scientific literature, unpublished research projects and citizen science.

This material is available as part of online article from:
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