Spatial distribution patterns of the non-native European catfish (Silurus glanis) from multiple online sources – a case study for River Tagus (Iberian Peninsula)

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**ABSTRACT**

Effective management of invasive fishes depends on the availability of updated information about their distribution and spatial dispersion. Forensic analysis was performed using online and published data on the European catfish, *Silurus glanis* Linnaeus, 1758, a recent invader in the Tagus basin (Iberian Peninsula). Eighty records were obtained mainly from anglers’ fora and blogs and more recently from www.youtube.com. Since the first record in 1998, *S. glanis* expanded its geographic range by ≈ 700 km of river network, occurring mainly in reservoirs and in high order sections. Human-mediated and natural dispersal events were identified, with the former occurring during the first years of invasion and involving movements of > 50 km. Downstream dispersal directionality was predominant. This study demonstrates that the analysis of online data from anglers can provide useful information on the distribution and dispersal patterns of this non-native fish, potentially applicable as a preliminary, exploratory assessment tool for other non-native fishes.

Key words: Tagus, anglers, invasion, spread, reservoirs, protected areas
INTRODUCTION

The distribution and dispersal patterns of non-native species are key aspects of invasion biology, and this is particularly true for the Iberian Peninsula where invasive fishes have been introduced and dispersed by recreational fishermen (Elvira & Almodóvar 2001; Ribeiro & Veríssimo 2014; Banha & Anastácio 2015). Effective management of non-native fishes (NNF) requires updated and reliable information about their distribution in order to understand a species’ dispersion mechanisms and adapt management actions to control or limit its dispersal (Caffrey et al. 2014).

However, monitoring programmes can be very costly, so alternative, low-cost data sources are needed, and one potential source is the main recreational stakeholder: anglers.

As in several countries (e.g. Cooke & Cowx 2004; Cowx 2015), recreational anglers in the Iberian Peninsula number nearly one million persons (Ferreira et al. 2010; Ministerio de Agricultura, Alimentación e Medio Ambiente 2012) from which important information could be acquired. And anglers now frequently use social media to share their experiences through online platforms (blogs, social networks, fishery websites), which increases the amount of information about NNF that can be useful for environmental managers and scientists in a manner analogous to citizen science (Cohn 2008; Roy et al. 2015).

The European catfish *Silurus glanis* Linnaeus, 1758 (Siluriformes, Siluridae), previously known as sheatfish, has a native distribution that extends from Western Asia to Germany and Flanders (Verreycken et al. 2007; Copp et al. 2009) in North, Baltic, Black, Caspian and Aral Sea basins (Kottelat & Freyof 2007). Owing to its potential to achieve very large size and its value as a foodstuff, *S. glanis* has been introduced to other European countries for aquaculture and/or as a highly prized trophy fish (Copp et al. 2009). In 1974, *S. glanis* was introduced to the eastern part of the Iberian Peninsula (Carol et al. 2003; Benejam et al. 2007), but subsequent records originate from western Spain (Pérez-Bote & Roso 2009; Moreno-Valcárcel et al. 2013) and
Portugal (Gkenas et al. 2015). In the River Tagus basin, angler records on internet sites vastly outnumber the few confirmed occurrences of S. glanis in the scientific literature, resulting in contradictory distribution maps. The S. glanis is a perfect model species to assess whether unverified, scattered information recorded online by anglers could provide potentially accurate species distribution and dispersal patterns in the River Tagus, which is Iberia’s largest river catchment. Therefore, the aim of the present study is to evaluate this potential use of anglers’ online records, with the specific objectives to: 1) obtain an up-to-date scenario about S. glanis current distribution; 2) determine the temporal variation of S. glanis invaded range; 3) evaluate the invasion dispersal patterns of S. glanis through time; 4) estimate which types of river habitats are more prone to invasion; and 5) calculate the proximity of the invaded range to natural protected areas in the River Tagus basin. The potential use of the information gathered here to enhance NNF management practices is discussed.

MATERIAL AND METHODS

An extensive search for Silurus glanis records was performed using different sources of information, namely literature, news and social media websites (e.g. Youtube, Facebook, Instagram), online resource databases and search engines (e.g. Google), and websites dedicated specifically to anglers (e.g. Iberian fishing forums and blogs). A Boolean search with AND, OR and NEAR as Boolean operators was performed during April and May of 2015 using different combinations of keywords, including common and scientific designators for the species (i.e. Silurus, Siluro, European catfish, Wels catfish) and for the drainage (i.e. Tejo, Tajo, Tagus). Following the protocol of Banha et al. (2015), an information source was accepted as a confirmed record of the species only when it included the locality, year and accompanying
Whenever the same catch record was reported by more than one source (recognized by the use of exactly the same picture and/or video), only the earliest record was retained. The geographical coordinates were extracted from Google Maps and when a reservoir name was given as locality, the coordinates from the reservoir midpoint were used. As described in Cañedo-Argüelles et al. (2015), distances between records were estimated as the river network distance, i.e. the number of km separating each pair of locations, using the Network Analyst extension within ArcMap. The temporal change in the maximum observed distances between *S. glanis* records in the Tagus drainage was obtained using the two most distant records for each year.

In an attempt to identify and classify whether or not new records of *S. glanis* were due to natural dispersal or to human-mediated introductions, the shortest distance (within the river network) between a new (species) record and previous records was calculated. Preliminary analysis of the data suggested two periods of minimum distances: Period 1) records prior to 2010, representing *S. glanis* initial establishment in the drainage, with nearly 30 records and corresponding to the first three *S. glanis* generations - generation time is 4 years (Copp et al. 2009), with some long range records (more than 100 km); and Period 2) records between 2010 and 2015 inclusive, which represents a secondary invasion stage with established *S. glanis* populations in the wild showing short distance records (less than 100 km) (Table 1). This chronological division allowed differences in the patterns of the invasion spread to be compared among periods with a representative sample size. Frequency histograms with the minimum distance of a new record to previous ones were constructed for both periods. Additionally, distribution maps were constructed in ArcMap 10.1 based on the species records for these two time periods. For Period 2, a power function \( y = a \times x^b \) was fitted to the relative frequencies of natural spread distances (i.e. species diffusion) of *S. glanis* per year. This function is much
simpler than other commonly-used functions, e.g. Weibull (Lockwood et al. 2007). In fact, based on visual evaluation of model fit and $r^2$, the power function had a better fit to the observed long-tailed, heavily skewed dispersal data. Dispersion directionality for *S. glanis* was estimated from the distance matrices (periods 1 and 2). The pair-wise distance was set to negative for new records located downstream of previous records, whereas the same distance was set to positive for new records located upstream of previous records. Also, records registered at the same locality (i.e. distance = 0) were excluded from analysis.

To evaluate which habitat types are more prone to invasion by *S. glanis*, records were cross-referenced with environmental descriptors using two variables: stream order and reservoir presence. Data for these variables were obtained from several “shapefiles”, all available online: Rivers and respective stream order ([www.eea.europa.eu/data-and-maps/data/european-catchments-and-rivers-network](http://www.eea.europa.eu/data-and-maps/data/european-catchments-and-rivers-network)); European catchments and Rivers network system (Ecrins; [http://intersig-web.inag.pt/intersig/mapas.aspx](http://intersig-web.inag.pt/intersig/mapas.aspx)); INAG (currently “Agência Portuguesa do Ambiente”); and Spanish and other international reservoirs ([www.gwsp.org/products/grand-database.html](http://www.gwsp.org/products/grand-database.html)); and Global Water System Project circa 2010 (Lehner et al. 2011). These files also enabled the calculation of the total stream/river length and the proportions of river network within each stream order. The Standardized Forage Ratio (Chesson 1983) was calculated to determine *S. glanis* habitat preferences in terms of stream order: $S_i = \frac{r_i/p_i}{\sum_{n=1}^{i} (r_i/p_i)}$ where $r_i$ is the proportion of the environmental descriptor classes ($i$) calculated among the records registered, $p_i$ is the proportion of the descriptor class $i$ found in the environment and $n$ is the number of habitats. The value of $S_i$ ranges between 0 and 1, with $S_i = 0$ indicating habitat avoidance and $S_i = 1$ representing exclusive use of habitat type $i$.

Additionally, to visually check if each record came from a reservoir (some small reservoirs were
not included in the shapefiles), aerial images from ArcGIS (Basemap – World Imagery) were used.

The distance between invaded sections and natural protected areas was measured, as an indirect measure of the freshwater ecosystem susceptibility. Data from protected natural areas was obtained from two shapefiles available online: 1) Portuguese protected areas (www.icnf.pt/portal/naturaclas/cart), Instituto de Conservação da Natureza e das Florestas; and 2) Spanish protected areas (www.redeuroparc.org/descargasmapas.jsp), Europarc España. The distance of each record to the nearest national natural protected area was measured and mapped, enabling the identification of which natural protected areas are already invaded or about to be invaded.

RESULTS

A total of 80 records of *S. glanis* were registered at 39 different localities in the Tagus basin between 1998 and 2015 (Table 1, Figure 1). Nearly half of the records originated from anglers’ fora and blogs, with Youtube videos being the second source of information, and literature sources were the least informative (Table 1). Almost all of *S. glanis* records were after 2006, when a large increase in records was observed ranging from 20 to 31 records per three-year period (6–10 records year⁻¹).

The first confirmed records of *S. glanis* in the (upper) Tagus basin were near Madrid in 1998 and in two reservoirs, located in the central part, in 2001. Thereafter, *S. glanis* was captured predominantly in the middle section of the catchment, mainly between these locations, with a westward spread to lowlands in subsequent years (Fig. 1). In west (Portugal), most records were after 2010, with the westernmost record registered in 2015. A rapid geographic expansion of the invaded range of up to 500 km was observed in the first years, increasing slightly to a
maximum invaded range of 700 km, covering the main stretch of the river (Fig. 2). In Period 1, there were long distances (>100 km) between new *S. glanis* records, occurring further than 200 km apart. Whereas, in Period 2 almost all of the new records were found much closer (<50 km) (Fig. 3). According to the power function for Period 2 \( y = 2.57 \times x^{-1.51}, r^2 = 0.98, P < 0.001 \), 64% of the records are expected to occur within a 5 km range from the previous distribution and only 2% of the new records predictably occur beyond 50 km of previous records. Species dispersion directionality was predominantly downstream during Period 1 with some long distance records, with a mean value of \(-37.6 \pm 56.6 \text{ km year}^{-1}\) (95% CI) and by a median value of \(-2.2 \text{ km year}^{-1}\). In Period 2, *S. glanis* dispersion presents a weaker longitudinal directionality, with a mean value of \(-8.7 \pm 12.1 \text{ km year}^{-1}\) (95% CI) and a median value of \(-8.0 \text{ km year}^{-1}\).

Considering the stream orders, high \(S_i\) values were only found for the highest stream order (order 7, \(S_i=0.98\)), whereas \(S_i\) values lower than 0.02 were found for all others stream orders. Records found in low stream order sections (1 to 3) always coincided with reservoirs; indeed, *S. glanis* was found in reservoirs in nearly 83% of all registered records. Most records were located either inside (46%) or less than 30 km from a natural protected area (43%, Fig. 1).

**DISCUSSION**

The present study demonstrates that scattered fish records available online can reveal the progressive expansion of a NNF, with recreational anglers’ websites being the most important information source. The available online records were accompanied by temporal changes in the predominant source of information. It was only after 2006 that most of *S. glanis* reports started to be publicised online, more substantially in anglers’ fora and blogs, and more recently (from 2013) with media-sharing sites, probably due to its novelty amongst users (e.g. Youtube.com was only founded in 2005). The arrival of *S. glanis* to the different locations in the Tagus basin...
could have occurred earlier than reported due to the lack of online tools (or their limited knowledge). Nevertheless, the current approach has proved to be very practical, with 80 records of *S. glanis* being quickly available after a systematic online survey, which contrasts the five records available from the scientific literature. The unverified records constitute a first source of data that is easy accessible, cheap and immediate, contrary to scientific data, which often involve labour-intensive, costly surveys that can take extended periods to be published and may in some cases be of restricted access to the public.

In the present study was possible to identify *S. glanis* current distribution and how invasion of the River Tagus might have occurred: an initial stage, probably human-mediated, characterized by widely long distance introductions was followed by the current patterns of mainly short-distance natural dispersal. This initial putative human-mediated dispersal is the most plausible mechanism since the distant new records are beyond the limit of the species natural dispersal. In fact, *S. glanis* presents a low dispersal capacity, inferred from its mean distance travelled per day which is less than 50 m day$^{-1}$ (Carol *et al.* 2007; Danek *et al.* 2014). A rough estimation based on these telemetry studies suggests an approximate annual natural dispersion of about 20 km year$^{-1}$; however, long distance dispersal could occur in association with extreme hydrological events such as floods. Also, the adjusted power function of Period 2 seems to corroborate the previous data since the large majority (98%) of the records are expected to be within a 50 km range from previous distribution. Therefore, new species records beyond this limit are most likely due to human-mediated spread. Nevertheless, it should be noticed that factors like the permeability of the dams and weirs along with the presence and efficiency of fish passages were not assessed in this study, therefore short distance spread could also be considered human-mediated introductions, particularly when records are separated by these infrastructures. This observation is supported by Hermoso *et al.* (2011) that found riverine
reaches closer to reservoirs more invaded by non-native species, probably due to natural dispersal but also to short distance human mediated introductions. In this study the results suggest a prevalent downstream dispersal of *S. glanis* along the river network, by both dispersal mechanisms (human-mediated and natural dispersion). Such pattern is consistent with other NNF (Gante & Santos 2002; Ribeiro et al. 2006; Ribeiro et al. 2009) because *S. glanis* has expanded its distribution from eastern to central Iberia due to human-mediated introductions, most likely from the Ebro to the Tagus basin (Carol et al. 2003; Gkenas et al. 2015), and finally spread downstream.

The observed relations between geographic locations and environmental descriptors establish reservoirs and large river sections found in the highest stream order as *S. glanis* predominant habitat, which is consistent with previous work (Carol et al. 2007; Copp et al. 2009). Nevertheless, some caution is necessary when interpreting these data since the methodology used here could be biased by the locations preferred by anglers. In fact, Marta et al. (2001) refer reservoirs as the dominant anglers’ sites (97%) in the lower River Guadiana (Portugal).

The natural protected areas constitute high value zones where human activities must be managed to ensure biodiversity protection and social well-being. A great proportion of *S. glanis* records were found either inside national protected areas or very close to them. The knowledge of *S. glanis* impact on aquatic communities is important to assess the potential environmental and economic impact of the species, but this information is still limited (Copp et al. 2009; Guillerault et al. 2015). The species’ putative impact might be larger, given that only national protected areas were considered in the present study.

The general pattern of *S. glanis* invasion in the River Tagus shown in the present study should be interpreted as a first approach. In spite of some issues with regard to data reliability,
due to collection by inexperienced volunteers from invasive species monitoring programmes (Cohn 2008; Delaney et al. 2008), species identification reliability was mitigated by more experienced and knowledgeable anglers, who have proved reliable in other citizen science projects (Granek et al. 2008; Raghavan et al. 2011; Pinder et al. 2015; Hargrove et al. 2015). In fact, online posts from anglers’ web fora were already used as first source of information to detect the NNF Perca fluviatilis (L.) and Rutilus rutilus (L.) in Portugal (Banha et al. 2015; Ribeiro & Veríssimo 2014). However, anglers and even scientists can misidentify lesser known species (e.g. the case of the Alpine cyprinid, riffle minnow Leuciscus souffia, mistakenly reported (Araújo et al. 1999) for the upper Thames Estuary (see Copp et al. 2007). For this reason, a conservative approach was adopted regarding acceptance of a record as valid. Furthermore, reliable literature records confirmed the species distribution and invasion pattern in the Tagus basin, namely the first and most upstream record (Goméz 2005) and the most recent and downstream record (Gkenas et al. 2015).

The methodology used in the present study was considered very useful, cost-efficient and reliable to gain updated information about a species in need of management efforts. The early detection of NNF species, the determination of its invasion range, and the understanding of the species’ invasion patterns are key factors for non-native species management. Furthermore, the majority of internet resources are interactive sites (e.g. direct messages), which offer a unique opportunity for use as an educational tool targeted directly at a principal stakeholder group to enhance its environmental awareness. This could aid in the reduction of the number and spread of new invasive NNF and ultimately contribute to the protection of endangered native fishes endemic to the Iberian Peninsula.

REFERENCES


Table 1. Number of *Silurus glanis* records per time period in River Tagus basin between 1998 and 2015 from various information sources: Literature (papers and books); Fishing sites (forums, blogs and sites); Media (newspapers, magazines, television); Youtube.com; Other (tourist promoters sites, environmental groups, popular science sites, Instagram.com, Flickr.com, Facebook.com)

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<th>Youtube</th>
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<td>1</td>
<td>2</td>
<td>0</td>
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<td>2</td>
<td>17</td>
<td>3</td>
<td>1</td>
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<tr>
<td>2010–2012</td>
<td>20</td>
<td>0</td>
<td>12</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2013–2015</td>
<td>31</td>
<td>2</td>
<td>7</td>
<td>4</td>
<td>10</td>
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<tr>
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<td>80</td>
<td>5</td>
<td>38</td>
<td>10</td>
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**Figure 1.** Map of the River Tagus catchment highlighted in grey within (a) the Iberian Peninsula (Inset: P = Portugal, S = Spain), with (b) the locations of *Silurus glanis* records during the two periods analysed (white circles = Period 1 = records prior to 2010; black circles = Period 2 = records after 2010), with national protected areas highlighted with grey shading.

**Figure 2.** Temporal change of maximum observed distances between *Silurus glanis* records within the River Tagus basin.

**Figure 3.** Frequency histograms for: Period 1 (upper graph, records before 2010; *denotes one record [distance of 487 Km] removed to improve clarity); and Period 2 (lower graph, records after 2010), based on the minimum river network distance between new records to the previous distribution (solid line represents a power function of estimated probabilities of dispersal).
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102x64mm (300 x 300 DPI)
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