



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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3 1 **Spatial distribution patterns of the non-native European catfish (*Silurus glanis*) from multiple**
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5 2 **online sources – a case study for River Tagus (Iberian Peninsula)**
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10 4 ABSTRACT

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12 5 Effective management of invasive fishes depends on the availability of updated information
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14 6 about their distribution and spatial dispersion. Forensic analysis was performed using online and
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16 7 published data on the European catfish, *Silurus glanis* Linnaeus, 1758, a recent invader in the
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18 8 Tagus basin (Iberian Peninsula). Eighty records were obtained mainly from anglers' fora and
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20 9 blogs and more recently from www.youtube.com. Since the first record in 1998, *S. glanis*
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22 10 expanded its geographic range by ≈ 700 km of river network, occurring mainly in reservoirs and
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24 11 in high order sections. Human-mediated and natural dispersal events were identified, with the
25
26 12 former occurring during the first years of invasion and involving movements of > 50 km.
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28 13 Downstream dispersal directionality was predominant. This study demonstrates that the
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30 14 analysis of online data from anglers can provide useful information on the distribution and
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32 15 dispersal patterns of this non-native fish, potentially applicable as a preliminary, exploratory
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34 16 assessment tool for other non-native fishes.
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42 18 Key words: Tagus, anglers, invasion, spread, reservoirs, protected areas
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20 INTRODUCTION

21 The distribution and dispersal patterns of non-native species are key aspects of invasion biology,
22 and this is particularly true for the Iberian Peninsula where invasive fishes have been introduced
23 and dispersed by recreational fishermen (Elvira & Almodóvar 2001; Ribeiro & Veríssimo 2014;
24 Banha & Anastácio 2015). Effective management of non-native fishes (NNF) requires updated
25 and reliable information about their distribution in order to understand a species' dispersion
26 mechanisms and adapt management actions to control or limit its dispersal (Caffrey *et al.* 2014).
27 However, monitoring programmes can be very costly, so alternative, low-cost data sources are
28 needed, and one potential source is the main recreational stakeholder: anglers.

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

36 The European catfish *Silurus glanis* Linnaeus, 1758 (Siluriformes, Siluridae), previously
37 known as sheatfish, has a native distribution that extends from Western Asia to Germany and
38 Flanders (Verreycken *et al.* 2007; Copp *et al.* 2009) in North, Baltic, Black, Caspian and Aral Sea
39 basins (Kottelat & Freyof 2007). Owing to its potential to achieve very large size and its value as
40 a foodstuff, *S. glanis* has been introduced to other European countries for aquaculture and/or as
41 a highly prized trophy fish (Copp *et al.* 2009). In 1974, *S. glanis* was introduced to the eastern
42 part of the Iberian Peninsula (Carol *et al.* 2003; Benejam *et al.* 2007), but subsequent records
43 originate from western Spain (Pérez-Bote & Roso 2009; Moreno-Valcárcel *et al.* 2013) and

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3 44 Portugal (Gkenas *et al.* 2015). In the River Tagus basin, angler records on internet sites vastly
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5 45 outnumber the few confirmed occurrences of *S. glanis* in the scientific literature, resulting in
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7 46 contradictory distribution maps.
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10 47 The *S. glanis* is a perfect model species to assess whether unverified, scattered information
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12 48 recorded online by anglers could provide potentially accurate species distribution and dispersal
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14 49 patterns in the River Tagus, which is Iberia's largest river catchment. Therefore, the aim of the
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16 50 present study is to evaluate this potential use of anglers' online records, with the specific
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18 51 objectives to: 1) obtain an up-to-date scenario about *S. glanis* current distribution; 2) determine
19
20 52 the temporal variation of *S. glanis* invaded range; 3) evaluate the invasion dispersal patterns of
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22 53 *S. glanis* through time; 4) estimate which types of river habitats are more prone to invasion; and
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24 54 5) calculate the proximity of the invaded range to natural protected areas in the River Tagus
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26 55 basin. The potential use of the information gathered here to enhance NNF management
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28 56 practices is discussed.
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34 58 MATERIAL AND METHODS

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37 59 An extensive search for *Silurus glanis* records was performed using different sources of
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39 60 information, namely literature, news and social media websites (e.g. Youtube, Facebook,
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41 61 Instagram), online resource databases and search engines (e.g. Google), and websites dedicated
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43 62 specifically to anglers (e.g. Iberian fishing forums and blogs). A Boolean search with AND, OR and
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45 63 NEAR as Boolean operators was performed during April and May of 2015 using different
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47 64 combinations of keywords, including common and scientific designators for the species (i.e.
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49 65 *Silurus*, *Siluro*, European catfish, Wels catfish) and for the drainage (i.e. Tejo, Tajo, Tagus).
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51 66 Following the protocol of Banha *et al.* (2015), an information source was accepted as a
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53 67 confirmed record of the species only when it included the locality, year and accompanying
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3 68 media (picture or video). Whenever the same catch record was reported by more than one
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5 69 source (recognized by the use of exactly the same picture and/or video), only the earliest record
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8 70 was retained. The geographical coordinates were extracted from *Google Maps* and when a
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10 71 reservoir name was given as locality, the coordinates from the reservoir midpoint were used. As
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12 72 described in Cañedo-Argüelles *et al.* (2015), distances between records were estimated as the
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14 73 river network distance, i.e. the number of km separating each pair of locations, using the
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17 74 Network Analyst extension within ArcMap. The temporal change in the maximum observed
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19 75 distances between *S. glanis* records in the Tagus drainage was obtained using the two most
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21 76 distant records for each year.
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24 77 In an attempt to identify and classify whether or not new records of *S. glanis* were due to
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26 78 natural dispersal or to human-mediated introductions, the shortest distance (within the river
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28 79 network) between a new (species) record and previous records was calculated. Preliminary
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30 80 analysis of the data suggested two periods of minimum distances: Period 1) records prior to
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32 81 2010, representing *S. glanis* initial establishment in the drainage, with nearly 30 records and
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34 82 corresponding to the first three *S. glanis* generations - generation time is 4 years (Copp *et al.*
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36 83 2009), with some long range records (more than 100 km); and Period 2) records between 2010
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38 84 and 2015 inclusive, which represents a secondary invasion stage with established *S. glanis*
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40 85 populations in the wild showing short distance records (less than 100 km) (Table 1). This
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42 86 chronological division allowed differences in the patterns of the invasion spread to be compared
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44 87 among periods with a representative sample size. Frequency histograms with the minimum
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46 88 distance of a new record to previous ones were constructed for both periods. Additionally,
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48 89 distribution maps were constructed in ArcMap 10.1 based on the species records for these two
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50 90 time periods. For Period 2, a power function ($y = a \times \chi^b$) was fitted to the relative frequencies of
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52 91 natural spread distances (i.e. species diffusion) of *S. glanis* per year. This function is much
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3 92 simpler than other commonly-used functions, e.g. Weibull (Lockwood *et al.* 2007). In fact, based
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5 93 on visual evaluation of model fit and r^2 , the power function had a better fit to the observed long-
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8 94 tailed, heavily skewed dispersal data. Dispersion directionality for *S. glanis* was estimated from
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10 95 the distance matrices (periods 1 and 2). The pair-wise distance was set to negative for new
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12 96 records located downstream of previous records, whereas the same distance was set to positive
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15 97 for new records located upstream of previous records. Also, records registered at the same
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17 98 locality (i.e. distance = 0) were excluded from analysis.

19 99 To evaluate which habitat types are more prone to invasion by *S. glanis*, records were cross
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21 100 referenced with environmental descriptors using two variables: stream order and reservoir
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23 101 presence. Data for these variables were obtained from several “shapefiles”, all available online:
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25 102 Rivers and respective stream order ([www.eea.europa.eu/data-and-maps/data/european-](http://www.eea.europa.eu/data-and-maps/data/european-catchments-and-rivers-network)
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27 103 [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;
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29 104 Portuguese reservoirs: <http://intersig-web.inag.pt/intersig/mapas.aspx>); INAG (currently
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31 105 “Agência Portuguesa do Ambiente”); and Spanish and other international reservoirs
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33 106 (www.gwsp.org/products/grand-database.html); and Global Water System Project circa 2010
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35 107 (Lehner *et al.* 2011). These files also enabled the calculation of the total stream/river length and
36
37 108 the proportions of river network within each stream order. The Standardized Forage Ratio
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39 109 (Chesson 1983) was calculated to determine *S. glanis* habitat preferences in terms of stream
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41 110 order: $S_i = \frac{r_i/p_i}{\sum_{n=1}^n (r_n/p_n)}$ where r_i is the proportion of the environmental descriptor classes (i)
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43 111 calculated among the records registered, p_i is the proportion of the descriptor class i found in
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45 112 the environment and n is the number of habitats. The value of S_i ranges between 0 and 1, with S_i
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47 113 = 0 indicating habitat avoidance and $S_i = 1$ representing exclusive use of habitat type i .
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49 114 Additionally, to visually check if each record came from a reservoir (some small reservoirs were
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3 115 not included in the shapefiles), aerial images from ArcGIS (Basemap – World Imagery) were
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6 116 used.

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8 117 The distance between invaded sections and natural protected areas was measured, as an
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10 118 indirect measure of the freshwater ecosystem susceptibility. Data from protected natural areas
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12 119 was obtained from two shapefiles available online: 1) Portuguese protected areas
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14 120 (www.icnf.pt/portal/naturaclas/cart), Instituto de Conservação da Natureza e das Florestas; and
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17 121 2) Spanish protected areas (www.redeuroparc.org/descargasmapas.jsp), Europarc España. The
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19 122 distance of each record to the nearest national natural protected area was measured and
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21 123 mapped, enabling the identification of which natural protected areas are already invaded or
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23 124 about to be invaded.
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27 28 29 126 RESULTS

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31 127 A total of 80 records of *S. glanis* were registered at 39 different localities in the Tagus basin
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33 128 between 1998 and 2015 (Table 1, Figure 1). Nearly half of the records originated from anglers'
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35 129 fora and blogs, with Youtube videos being the second source of information, and literature
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37 130 sources were the least informative (Table 1). Almost all of *S. glanis* records were after 2006,
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39 131 when a large increase in records was observed ranging from 20 to 31 records per three-year
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41 132 period (6–10 records year⁻¹).
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44 133 The first confirmed records of *S. glanis* in the (upper) Tagus basin were near Madrid in 1998
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46 134 and in two reservoirs, located in the central part, in 2001. Thereafter, *S. glanis* was captured
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48 135 predominantly in the middle section of the catchment, mainly between these locations, with a
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50 136 westward spread to lowlands in subsequent years (Fig. 1). In west (Portugal), most records were
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52 137 after 2010, with the westernmost record registered in 2015. A rapid geographic expansion of
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54 138 the invaded range of up to 500 km was observed in the first years, increasing slightly to a
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3 139 maximum invaded range of 700 km, covering the main stretch of the river (Fig. 2). In Period 1,
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5 140 there were long distances (>100 km) between new *S. glanis* records, occurring further than 200
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8 141 km apart. Whereas, in Period 2 almost all of the new records were found much closer (<50 km)
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10 142 (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%
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12 143 of the records are expected to occur within a 5 km range from the previous distribution and only
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14 144 2% of the new records predictably occur beyond 50 km of previous records. Species dispersion
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16 145 directionality was predominantly downstream during Period 1 with some long distance records,
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18 146 with a mean value of -37.6 ± 56.6 km year⁻¹ (95% CI) and by a median value of -2.2 km year⁻¹. In
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20 147 Period 2, *S. glanis* dispersion presents a weaker longitudinal directionality, with a mean value of
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22 148 -8.7 ± 12.1 km year⁻¹ (95% CI) and a median value of -8.0 km year⁻¹.

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24 149 Considering the stream orders, high S_i values were only found for the highest stream order
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26 150 (order 7, $S_i=0.98$), whereas S_i values lower than 0.02 were found for all others stream orders.
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28 151 Records found in low stream order sections (1 to 3) always coincided with reservoirs; indeed, *S.*
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30 152 *glanis* was found in reservoirs in nearly 83% of all registered records. Most records were located
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32 153 either inside (46%) or less than 30 km from a natural protected area (43%, Fig. 1).
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40 155 DISCUSSION

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42 156 The present study demonstrates that scattered fish records available online can reveal the
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44 157 progressive expansion of a NNF, with recreational anglers' websites being the most important
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46 158 information source. The available online records were accompanied by temporal changes in the
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48 159 predominant source of information. It was only after 2006 that most of *S. glanis* reports started
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50 160 to be publicised online, more substantially in anglers' fora and blogs, and more recently (from
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52 161 2013) with media-sharing sites, probably due to its novelty amongst users (e.g. Youtube.com
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54 162 was only founded in 2005). The arrival of *S. glanis* to the different locations in the Tagus basin
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3 163 could have occurred earlier than reported due to the lack of online tools (or their limited
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5 164 knowledge). Nevertheless, the current approach has proved to be very practical, with 80 records
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8 165 of *S. glanis* being quickly available after a systematic online survey, which contrasts the five
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10 166 records available from the scientific literature. The unverified records constitute a first source of
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12 167 data that is easy accessible, cheap and immediate, contrary to scientific data, which often
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15 168 involve labour-intensive, costly surveys that can take extended periods to be published and may
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17 169 in some cases be of restricted access to the public.

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20 170 In the present study was possible to identify *S. glanis* current distribution and how invasion
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22 171 of the River Tagus might have occurred: an initial stage, probably human-mediated,
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24 172 characterized by widely long distance introductions was followed by the current patterns of
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26 173 mainly short-distance natural dispersal. This initial putative human-mediated dispersal is the
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28 174 most plausible mechanism since the distant new records are beyond the limit of the species
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30 175 natural dispersal. In fact, *S. glanis* presents a low dispersal capacity, inferred from its mean
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32 176 distance travelled per day which is less than 50 m day⁻¹ (Carol *et al.* 2007; Danek *et al.* 2014). A
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34 177 rough estimation based on these telemetry studies suggests an approximate annual natural
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36 178 dispersion of about 20 km year⁻¹; however, long distance dispersal could occur in association
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38 179 with extreme hydrological events such as floods. Also, the adjusted power function of Period 2
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40 180 seems to corroborate the previous data since the large majority (98%) of the records are
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42 181 expected to be within a 50 km range from previous distribution. Therefore, new species records
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44 182 beyond this limit are most likely due to human-mediated spread. Nevertheless, it should be
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46 183 noticed that factors like the permeability of the dams and weirs along with the presence and
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48 184 efficiency of fish passages were not assessed in this study, therefore short distance spread could
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50 185 also be considered human-mediated introductions, particularly when records are separated by
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52 186 these infrastructures. This observation is supported by Hermoso *et al.* (2011) that found riverine
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3 187 reaches closer to reservoirs more invaded by non-native species, probably due to natural
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5 188 dispersal but also to short distance human mediated introductions. In this study the results
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7
8 189 suggest a prevalent downstream dispersal of *S. glanis* along the river network, by both dispersal
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10 190 mechanisms (human-mediated and natural dispersion). Such pattern is consistent with other
11
12 191 NNF (Gante & Santos 2002; Ribeiro *et al.* 2006; Ribeiro *et al.* 2009) because *S. glanis* has
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14 192 expanded its distribution from eastern to central Iberia due to human-mediated introductions,
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16 193 most likely from the Ebro to the Tagus basin (Carol *et al.* 2003; Gkenas *et al.* 2015), and finally
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18 194 spread downstream.

19 195 The observed relations between geographic locations and environmental descriptors
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21 196 establish reservoirs and large river sections found in the highest stream order as *S. glanis*
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23 197 predominant habitat, which is consistent with previous work (Carol *et al.* 2007; Copp *et al.*
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25 198 2009). Nevertheless, some caution is necessary when interpreting these data since the
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27 199 methodology used here could be biased by the locations preferred by anglers. In fact, Marta *et*
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29 200 *al.* (2001) refer reservoirs as the dominant anglers' sites (97%) in the lower River Guadiana
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31 201 (Portugal).

32
33 202 The natural protected areas constitute high value zones where human activities must be
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35 203 managed to ensure biodiversity protection and social well-being. A great proportion of *S. glanis*
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37 204 records were found either inside national protected areas or very close to them. The knowledge
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39 205 of *S. glanis* impact on aquatic communities is important to assess the potential environmental
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41 206 and economic impact of the species, but this information is still limited (Copp *et al.* 2009;
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43 207 Guillerault *et al.* 2015). The species' putative impact might be larger, given that only national
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45 208 protected areas were considered in the present study.

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47 209 The general pattern of *S. glanis* invasion in the River Tagus shown in the present study
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49 210 should be interpreted as a first approach. In spite of some issues with regard to data reliability,
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3 211 due to collection by inexperienced volunteers from invasive species monitoring programmes
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5 212 (Cohn 2008; Delaney *et al.* 2008), species identification reliability was mitigated by more
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7 213 experienced and knowledgeable anglers, who have proved reliable in other citizen science
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9 214 projects (Granek *et al.* 2008; Raghavan *et al.* 2011; Pinder *et al.* 2015; Hargrove *et al.* 2015). In
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11 215 fact, online posts from anglers' web fora were already used as first source of information to
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13 216 detect the NNF *Perca fluviatilis* (L.) and *Rutilus rutilus* (L.) in Portugal (Banha *et al.* 2015; Ribeiro
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15 217 & Veríssimo 2014). However, anglers and even scientists can misidentify lesser known species
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17 218 (e.g. the case of the Alpine cyprinid, riffle minnow *Leuciscus souffia*, mistakenly reported (Araújo
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19 219 *et al.* 1999) for the upper Thames Estuary (see Copp *et al.* 2007). For this reason, a conservative
20
21 220 approach was adopted regarding acceptance of a record as valid. Furthermore, reliable
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23 221 literature records confirmed the species distribution and invasion pattern in the Tagus basin,
24
25 222 namely the first and most upstream record (Goméz 2005) and the most recent and downstream
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27 223 record (Gkenas *et al.* 2015).

28
29 224 The methodology used in the present study was considered very useful, cost-efficient and
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31 225 reliable to gain updated information about a species in need of management efforts. The early
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33 226 detection of NNF species, the determination of its invasion range, and the understanding of the
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35 227 species' invasion patterns are key factors for non-native species management. Furthermore, the
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37 228 majority of internet resources are interactive sites (e.g. direct messages), which offer a unique
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39 229 opportunity for use as an educational tool targeted directly at a principal stakeholder group to
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41 230 enhance its environmental awareness. This could aid in the reduction of the number and spread
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43 231 of new invasive NNF and ultimately contribute to the protection of endangered native fishes
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45 232 endemic to the Iberian Peninsula.
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3 345 Table 1. Number of *Silurus glanis* records per time period in River Tagus basin between 1998 and
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5 346 2015 from various information sources: Literature (papers and books); Fishing sites (forums,
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7 347 blogs and sites); Media (newspapers, magazines, television); Youtube.com; Other (tourist
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9 348 promoters sites, environmental groups, popular science sites, Instagram.com, Flickr.com,
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11 349 Facebook.com)

| Period | Nr. | Source | | | | |
|-----------|-----|------------|---------------|-------|---------|-------|
| | | Literature | Fishing sites | Media | Youtube | Other |
| < 2006 | 4 | 1 | 2 | 0 | 0 | 1 |
| 2007–2009 | 25 | 2 | 17 | 3 | 1 | 2 |
| 2010–2012 | 20 | 0 | 12 | 3 | 3 | 2 |
| 2013–2015 | 31 | 2 | 7 | 4 | 10 | 8 |
| Total | 80 | 5 | 38 | 10 | 14 | 13 |

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3 352 **Figure 1.** Map of the River Tagus catchment highlighted in grey within (a) the Iberian Peninsula
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5 353 (Inset: P = Portugal, S = Spain), with (b) the locations of *Silurus glanis* records during the two
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7 354 periods analysed (white circles = Period 1 = records prior to 2010; black circles = Period 2 =
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9 355 records after 2010), with national protected areas highlighted with grey shading.
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14 357 **Figure 2.** Temporal change of maximum observed distances between *Silurus glanis* records
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17 358 within the River Tagus basin.
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21 360 **Figure 3.** Frequency histograms for: Period 1 (upper graph, records before 2010; *denotes one
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23 361 record [distance of 487 Km] removed to improve clarity); and Period 2 (lower graph, records
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25 362 after 2010), based on the minimum river network distance between new records to the previous
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27 363 distribution (solid line represents a power function of estimated probabilities of dispersal).
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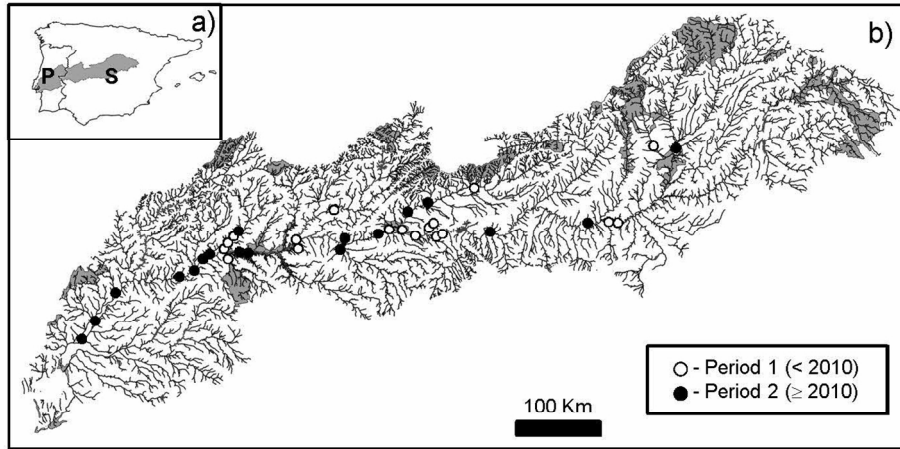


Figure 1. Map of the River Tagus catchment highlighted in grey within (a) the Iberian Peninsula (Inset: P = Portugal, S = Spain), with (b) the locations of *Silurus glanis* records during the two periods analysed (white circles = Period 1 = records prior to 2010; black circles = Period 2 = records after 2010), with national protected areas highlighted with grey shading.
194x105mm (200 x 200 DPI)

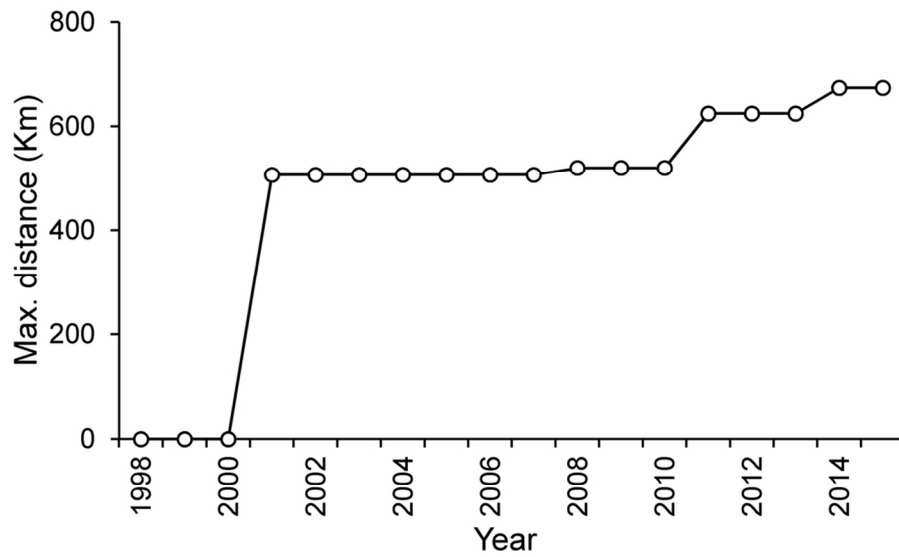


Figure 2. Temporal change of maximum observed distances between *Silurus glanis* records within the River Tagus basin.
102x64mm (300 x 300 DPI)

Review Only

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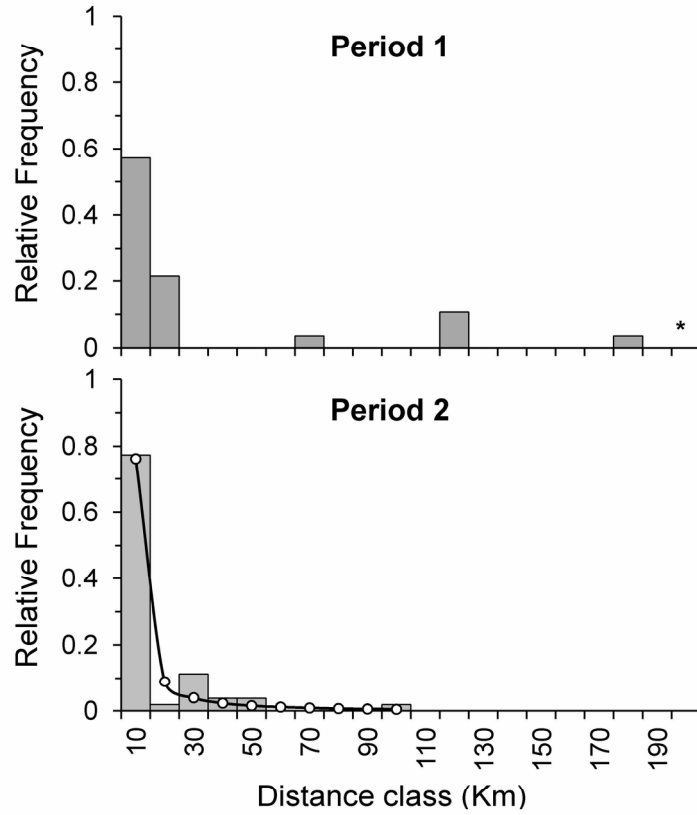


Figure 3. Frequency histograms for: Period 1 (upper graph, records before 2010; *denotes one record [distance of 487 Km] removed to improve clarity); and Period 2 (lower graph, records after 2010), based on the minimum river network distance between new records to the previous distribution (solid line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

177x168mm (300 x 300 DPI)