**João Pereira da Silva**

**De:** Joaquim Ruas
**Enviado:** segunda-feira, 5 de Janeiro de 2015 10:54
**Para:** Abel Baptista; Assunção Ferreira; Bruno Ribeiro Tavares; Cristóvão Norte; Diva Pinto; Fernando Jesus; Fernando Marques; Manuel Isaac; Filomena de Mello; Grupo Parlamentar Os Verdes; Helena Pinto; Hugo Almeida; Isabel Guerreiro Ferreira; Isabel Santos; João Pereira da Silva; João Ramos; Joaquim Ruas; Jorge Fão; José Luís Ferreira; Luís Pedro Pimentel; Mafalda Monteiro; Manuel Mota; Maria José Moreno; Mário Simões; Marlene Pires; Miguel Freitas; Nelson Peralta; Nuno Serra; Pedro Alves; Pedro do Ó Ramos; Pedro Lynce; Renato Sampaio; Ricardo Moreira; Ricardo Oliveira; Rosa Maria Bastos Albernaz; Sofia Vale; Tiago Abreu; Ulisses Pereira; Vasco Cunha; Acácio Pinto; Afonso Oliveira; Ana Paula Vitorino; Ângela Guerra; António Prôa; Bruno Dias; Bruno Inácio; Cecília Honório; Eduardo Teixeira; Graça Mota; Heloísa Apolónia; Hermínia Azenha; João Paulo Pedrosa; João Paulo Viegas; João Portugal; Jorge Rodrigues Pereira; José Ribeiro e Castro; Lídia Bulcão; Mário Magalhães; Maurício Marques; Paulo Ribeiro de Campos; Rui Pedro Duarte; Teresa Costa Santos; Valter Ribeiro
**Assunto:** FW: Sobre PPL n.º 258/XII
**Anexos:** Ribeiro_FME_2009.pdf

Senhores Deputados
Segue informação sobre a PPL n.º 258/XII.
Cumprimentos.
Joaquim Ruas



Caro Dr. Joaquim Ruas,

Tive conhecimento sobre as alteracoes ao PPL n.º 258/XII sobre o ordenamento e gestão sustentável dos recursos aquícolas das águas interior.

Sou um dos especialistas europeus que estuda os impactos sobre os problemas das causados pelos peixes introduzidos (area em que fiz o meu doutoramento). Trabalho com peixes dulciaquicolas desde 1997, fui responsavel pela execucao da Carta Piscicola Nacional (projecto da AFN/ICNF, descontinuado), e tenho mais de 20 publicacoes cientificas nesta area. Sou o actual Presidente da Sociedade Iberica de Ictiologia.

E' com enorme apreensao que vejo que remocao da obrigatoriedade da carta de Pescador. Isto porque a pesca desportiva (concretamente o desconhecimento dos pescadores nos impactos causados) e' o principal vector de introducao ilegal de peixes em Portugal. So' nos ultimos dois anos foram detectados 5 novas especies, com enormes impactos nos ecosistemas aquaticos, concretamente que aumentam os gastos com a conservacao e gestao sustentavel dos recursos aquicolas.

Envio em anexo um trabalho cientifico de 2009 com o estado da situacao 'a data da publicacao.

Envio tambem duas entrevistas que dei sobre este assunto. A noticia da SIC e' de 4 minutos sobre o peixe-gato europeu. Enquanto que a entrevista na Antena 1, (apartir do minuto 15 sensivelmente) demorou cerca de 20 minutos, e' sobre os problemas dos peixes introduzidos.

Gostaria que divulgasse esta mensagem pelos restantes membros da CAM.

Cumprimentos e votos de bom ano de 2015

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Filipe Ribeiro

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Center for Oceanography

Projects:
www.biodiversity4all.org
www.cartapiscicola.org

Fisheries Management and Ecology

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# Non-native fish in the fresh waters of Portugal, Azores and Madeira Islands: a growing threat to aquatic biodiversity

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**Abstract** Portugal, the Azores, and Madeira had a combined total of twenty six non-native fish species introductions, with the mainland having the highest number (twenty three), followed by the Azores with ten and Madeira with two records. Fifteen of these species established in Portugal, six in the Azores and one in Madeira. The oldest known introduction (1792) was goldfish, *Carassius auratus* (L.), while the newest (2005) was tinfoil barb, *Barbonymus schwanenfeldii* (Bleeker). Ten species had been introduced in Portugal by the beginning of 20th century, but the rate of introduction continues to increase, with four species introduced since 2000. In mainland Portugal, the Douro, the Tejo and the Guadiana drainages had the highest number of introduction records, while the Lima and the Mira drainages had the fewest. Management measures are offered to reduce current rate of fish introductions in Portuguese watersheds.

KEYWORDS: biological invasions, conservation, failed introductions, fisheries, ornamental use.

## Introduction

Non-native fishes are recognised as one of the major causes of the worldwide decline of aquatic fauna (Cowx 1998; Clavero & García-Berthou 2005; Helfman 2007) and their increase is generally associated with loss of native biodiversity (Dukes & Mooney 1999; Collares-Pereira, Cowx & Coelho 2002; Cambray 2003). According to Stiassny (1998), in the next 30 years about one-third of all freshwater fish species may become extinct. In Mediterranean climate areas, it is estimated that 60–80% of native fish species are in danger of extinction within 50 years (Moyle & Leidy 1992; Helfman 2007). Prompt identification of new fish invaders, their dispersal and reasons for introduction are critical for developing appropriate management measures, especially eradication of undesirable species (Britton & Brazier 2006). This is particularly important in regions with a high rate of endemic fish with limited distributions that are imperiled, as is the case for the Iberian Peninsula (Doadrio 2002; Rogado, Alexandrino, Almeida, Alves, Bochechas, Cortes, Domingos, Filipe, Madeira & Magalhães 2005).

In Europe, non-native fish introductions were frequently made in the late 19th century by societies for acclimatisation (Copp, Bianco, Bogustskaya, Eros, Falka, Ferreira, Fox, Freyhof, Gozlan, Grabowska, Kovac, Moreno-Amich, Naseka, Penaz, Povz, Przybylski, Robillard, Russell, Stakėnas, Sumer, Vila-Gispert & Wiesner 2005b), but fish introductions have existed since the Medieval Period, due to the use of *Cyprinus carpio* L. by monastic religious orders (Almaça 1995; Balon 1995). Most introductions into European freshwaters during the 20th century were made for fishery purposes and aquaculture (e.g. Cowx 1997; Elvira & Almodóvar 2001; Hesthagen & Sandlund 2007), but more recently ornamental fish have become frequent invaders (Copp, Wesley & Vilizzi 2005a; Copp, Stakėnas & Davison 2006). Most of the freshwater fish introductions into Europe came from

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North America, with clear pathways within Europe (García-Berthou, Alcaraz, Pou-Rovira, Zamora, Coenders & Feo 2005; Jeschke & Strayer 2005). The Iberian Peninsula (Portugal and Spain) has received fish mainly via France, including species from central Europe (García-Berthou *et al.* 2005; Leprieur, Beauchard, Huguény, Grenouillet & Brosse 2008). There are also several species native to the Iberian Peninsula that have been moved to watersheds to which they were not previously found (Elvira & Almodóvar 2001). These translocated species may have detrimental effects on native fish communities as much as other non-natives (e.g. Brown & Moyle 1997).

Despite the recent increase in research on fish invasions (García-Berthou 2007; Helfman 2007), information about key stages of the invasion process is still scarce, especially the transport and release stages (Moyle & Marchetti 2006; García-Berthou 2007). Failed introductions are poorly documented and existing information is scattered in regional publications, agency reports and other grey literature; in addition data on translocated species is generally disregarded by researchers and their impact neglected. To fill this gap for Portuguese territories (Portugal, Azores and Madeira), the overview by Almaça (1995) for mainland Portugal was updated and expanded to include the Azores and Madeira, and evaluate the distribution, introduction history, success and spread of each species. The purpose was to evaluate the threat non-native fishes present to the endemic aquatic biota of the three regions and provide management measures to mitigate the problems and minimise the on-going spread.

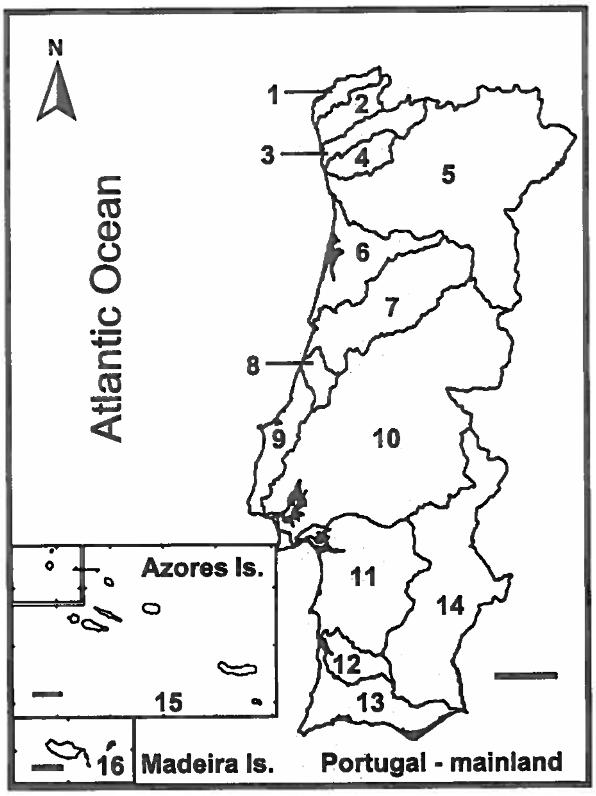


**Figure 1.** Map of Portugal, Azores and Madeira with the different drainages considered by National Water Institute: 1 = Minho; 2 = Lima; 3 = Cávado; 4 = Ave; 5 = Douro; 6 = Vouga; 7 = Mondego; 8 = Lis; 9 = Western; 10 = Tejo; 11 = Sado; 12 = Mira; 13 = Southwest and Algarve; 14 = Guadiana; 15 = Azores Islands; 16 = Madeira Island (bars represent 50 km).

## Materials and methods

A review of the literature on non-native fishes in Portuguese watersheds (Portugal, Azores and Madeira Islands; Fig. 1) was conducted using published papers and technical reports posted online at http://www.cartapiscicola.org (Ribeiro *et al.* 2007a), supplemented by personal communications with other researchers. Iberian native species that were introduced into a watershed to which they were not native were also considered to be non-native species, regardless if they were native elsewhere in Portugal, i.e. a translocation.

For each non-native fish, the present status in Portuguese watersheds was assessed. A species introduction was considered successful if the species has self-sustaining populations in the wild and was considered as a failure if it no longer occurs in the wild after a documented introduction. Species with no recent information about their presence after a search of all available literature were considered to be failed introductions. In each region (mainland Portugal, Azores and Madeira), the establishment rate was calculated as the number of successful non-natives divided by the total number of introductions.

For each non-native fish, information was recorded on region of origin, year of detection, present distribution in Portugal, purpose of introduction and probable mechanism of spread. Year of detection of a non-native fish corresponds to the first confirmed record in any Portuguese watershed, even if a prior date of introduction was suspected but could not be exactly determined. The introduction rate is the number of non-native fish species introduced per year. The ratio of the number of natives and the total number of species present was calculated for each watershed. This ratio is a Zoogeographic Index because it measures the degree of invasion of a fish community present in a watershed, ranging between 1.0 (not invaded community) and 0.0 (community containing only non-native species) (Elvira 1995).

## Results

The three Portuguese regions had records of 26 fish introductions, with the mainland having the highest number (23) of species, followed by the Azores (10) and Madeira Islands (2) (Table 1). In the Portuguese mainland, eight species did not become established, while in the Azores there were four species, and in Madeira *Salmo trutta* L. failed to become established in the wild (Table 1). The non-native fish establishment rate in Portuguese watersheds was high: 50% in Madeira, 60% in the Azores and 65% in the mainland. Most species introduced to the Azores and Madeira came from a smaller subset of the non-native fish in the mainland, but three species were exclusively introduced in the Azores [*Achondrostoma oligolepis* (Steindachner), *Rutilus rutilus* (L.) and *Perca fluviatilis* L.] (Table 1).

**Table 1.** Non-native fish species in the three Portuguese regions (Portugal, Azores and Madeira), geographic origin (A, Asia; E, central Europe; IP, Iberian Peninsula; NA, North America; SA, South America), reason for introduction, mechanism of spread, species status in each region: S = successful; F = failed

| Species | Authority | Origin | Reason | Mechanism of introduction and spread | Region of detection | | |
|---|---|---|---|---|---|---|---|
| | | | | | Portugal | Azores | Madeira |
| *Anguilla anguilla* | (Linnaeus, 1758) | IP | Fisheries | – | F | – | – |
| *Achondrostoma oligolepis* | (Steindachner, 1866) | IP | Naiveness | – | – | F | – |
| *Alburnus alburnus* | (Linnaeus, 1758) | E | Forage fish | Dispersion and translocation done by fishers | S | – | – |
| *Barbonymus schwanenfeldii* | (Bleeker, 1853) | A | Ornamental | – | F | – | – |
| *Barbus bocagei* | Steindachner, 1865 | IP | Fisheries | – | F | – | – |
| *Carassius auratus* | (Linnaeus, 1758) | A | Ornamental | Stocking programs | S | F | – |
| *Ctenopharyngodon idella* | (Valenciennes, 1844) | A | Biocontrol | – | F | – | – |
| *Cyprinus carpio* | Linnaeus, 1758 | E | Feeding | Stocking programs, dispersion and translocation done by fishers | S | S | – |
| *Gobio lozanoi** | Doadrio & Madeira 2004 | IP | Forage fish | Dispersion and translocation done by fishers | S | – | – |
| *Pseudochondrostoma polylepis* | (Steindachner, 1864) | IP | Fisheries | Stocking programs? | S | – | – |
| *Rutilus rutilus* | (Linnaeus, 1758) | E | Forage fish | – | – | S | – |
| *Tinca tinca* | (Linnaeus, 1758) | E | Feeding | Stocking programs | S | – | – |
| *Ameiurus melas* | (Rafinesque, 1820) | NA | Fisheries | Dispersion and translocation done by fishers | S | – | – |
| *Silurus glanis* | Linnaeus, 1758 | E | Fisheries | Dispersion | F | – | – |
| *Esox lucius* | Linnaeus, 1758 | E | Fisheries | Dispersion and stocking programs | S | S | – |
| *Oncorhynchus mykiss* | (Walbaum, 1792) | NA | Fisheries | Dispersion and stocking programs | S | S | S |
| *Salmo salar* | Linnaeus, 1758 | IP | Fisheries | Stocking programs | F | – | – |
| *Salmo trutta* | Linnaeus, 1758 | IP | Fisheries | Dispersion and stocking programs | F | F | F |
| *Salvelinus fontinalis* | (Mitchill, 1814) | NA | Fisheries | – | F | – | – |
| *Fundulus heteroclitus* | Linnaeus, 1758 | NA | Ornamental | Dispersion | S | – | – |
| *Gambusia holbrooki* | Girard, 1859 | NA | Biocontrol | Stocking programs, dispersion and translocation | S | – | – |
| *Lepomis gibbosus* | (Linnaeus, 1758) | NA | Ornamental | Dispersion and translocation done by people | S | – | – |
| *Micropterus salmoides* | (Lacepède, 1802) | NA | Fisheries | Dispersion and translocation done by fishers | S | F | – |
| *Perca fluviatilis* | (Linnaeus, 1758) | E | Fisheries | – | – | S | – |
| *Sander lucioperca* | (Linnaeus, 1758) | E | Fisheries | Dispersion and translocation done by fishers | S | S | – |
| *Australoheros facetus* | (Jenyns, 1842) | SA | Ornamental | Dispersion and translocation done by people | S | – | – |

**Gobio lozanoi* Doadrio & Madeira was formerly considered as *G. gobio* (L.), see Doadrio & Madeira (2004).

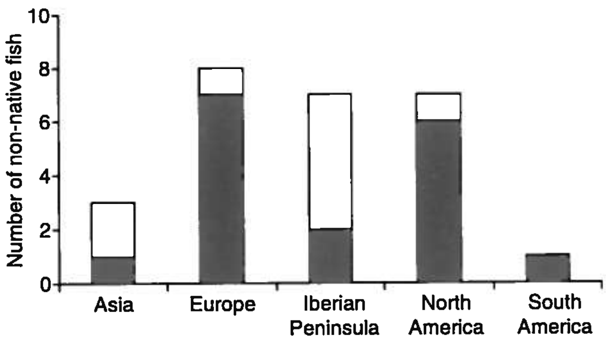


**Figure 2.** Successful (black) and non-established (white) non-native fish species per source region in Portuguese watersheds (mainland Portugal, Azores and Madeira).

The bulk of fish introductions came from three main geographic regions: Europe (30%), North America (27%) and the Iberian Peninsula (27%) (Fig. 2). Species that came from the Iberian Peninsula and Asia had a low success rate, with approximately 30% becoming successfully established, while this value was over 85% for central European and North American fishes (Fig. 2).

The main purpose of non-native fish introductions into Portuguese watersheds was for recreational fisheries, resulting in 16 introductions of which six failed to become established (Fig. 3). Ornamental fish was the second most important reason for introduction, with five species, *Carassius auratus* (L.), *Fundulus heteroclitus* L., *Lepomis gibbosus* (L.), *Australoheros facetus* (Jenyns) and *Barbonymus schwanenfeldii* (Bleeker) (Fig. 3; Table 1). The establishment of *B. schwanenfeldii* is not yet confirmed because of the novelty of its occurrence. Other reasons were responsible for two

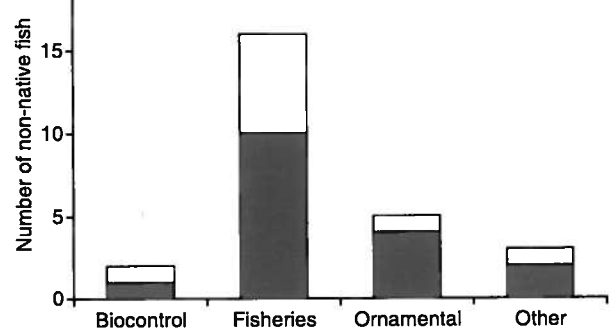


**Figure 3.** Number of non-native fish species in Portugal, Azores Islands and Madeira Island per reason for introduction, successfully established (black) and non-established (white).

failed [*A. oligolepis* and *Ctenopharyngodon idella* (Valenciennes)] and three successful [*C. carpio*, *Tinca tinca* (L.) and *Gambusia holbrooki* Girard] fish introductions (Fig. 3). The main mechanisms of spread were natural fish dispersion from other invaded regions, stocking programmes by fishery agencies, and illegal translocations by recreational fishers (Table 1).

Attempts to introduce a few fish species were made by the beginning of 20th century, with most introduced into the Azores (Table 1 and Fig. 4). Since then, the number of species introduced has been steadily increasing, but the introduction rate has increased considerably in the first years of the 21st Century (Fig. 4). The oldest known introduction was *C. auratus* in 1792, while the newest was *B. schwanenfeldii* in 2005 (Table 2).

In mainland Portugal, the Douro, Tejo and Guadiana drainages had the highest number of introduction records, while the Lima and Mira drainages together with Madeira had the lowest number of introductions (Table 2). The Zoogeographic Index was the highest in the Lima and Mira drainages suggesting that their native fish communities are relatively well preserved. Madeira and the Azores presented the lowest value because their rivers and lakes were once fishless. On the mainland, the Sado, Douro and Guadiana drainages presented the lowest values for the Zoogeographic Index (Table 2).

## Discussion

The introduction of new fish species into Portuguese waters represents a growing threat to native fishes and invertebrates (Clavero, Blanco-Garrido & Prenda 2004). The number of successful non-native freshwater fishes in Portuguese territories is increasing, with 17 species already representing 32% of the total freshwater fish fauna. Previous analyses underestimated the size of the threat. Almaça (1995) documented only 14 species, 12 successful, but his review did not include the Azores and Madeira or translocated species. In the present overview, 12 species were added to the list of introduced fishes of Portugal. Most of the non-native fishes came from central Europe and North America, which concurs with the general trend for Spain (Elvira & Almodóvar 2001) and Europe (Holcik 1991). The general pathway of entry into mainland Portugal was via Spain, which was mainly invaded from French populations, indicating the international nature of fish invasions (García-Berthou *et al.* 2005; Clavero & García-Berthou 2006).

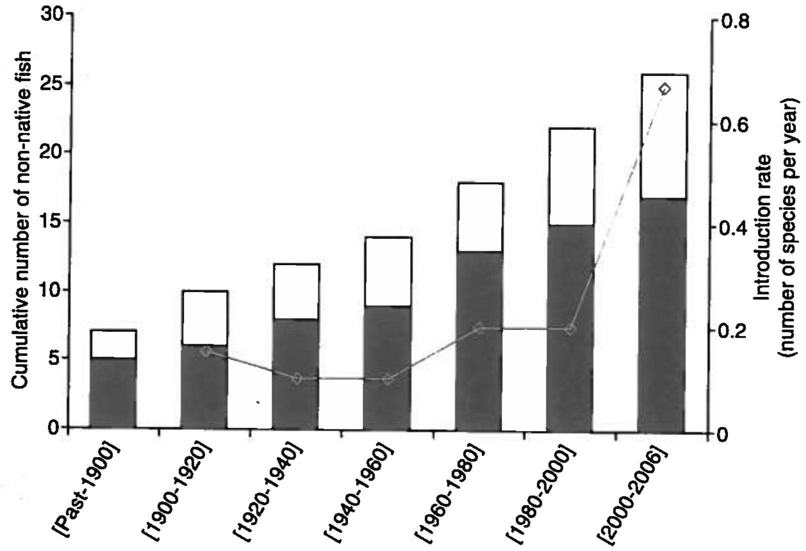


**Figure 4.** Temporal pattern of introduction of non-native fish species into Portuguese watersheds (mainland Portugal, Azores and Madeira Islands, $N = 16$) since the beginning of the 20th century – successfully established (black) and non-established (white) – and introduction rate (number of introductions per year). Each introduction into a new watershed is counted as a separate event. Note that the last bar represents only 6 years, rather than 20 years.

The Portuguese mainland has 15 successful non-native fishes, while there are 25 non-native fish species in Spanish inland waters (Elvira & Almodóvar 2001). The number of non-native fishes in France, Greece and Italy is also high, with 26, 23 and 25 species respectively (Keith & Allardi 1997; Bianco 1998; Economidis, Dimitriou, Pagoni, Michaloudi & Natsis 2000). This suggests that further invasions of Portuguese waters are imminent. However, these studies did not indicate which species have wild, self-sustaining populations and did not present information on native species introduced outside their native range. Generally, the information about translocated species and failed introductions is poorly reported probably because of lack of reliability in identifying species and the often informal nature of the introduction process. Nevertheless, having information on translocated species is as important, because: (1) their likely spread to other countries through international waterways; (2) their impacts on the invaded ecosystems can be large; (3) the absence of such data reduces the value of comparisons between successful and failed introductions in different areas (e.g. Marchetti, Moyle & Levine 2004; Ribeiro, Elvira, Collares-Pereira & Moyle 2008); and (4) the information can be helpful to managers by showing pathways of introduction.

The negative effects of most introduced fishes are poorly documented in Portugal (but see Ribeiro, Orjuela, Magalhães & Collares-Pereira 2007b). Their effects have probably been the highest in the originally fishless Azores and Madeira, where introductions have surely altered the food webs and other aspects of the aquatic ecosystems (Lehtonen 2002), with irreversible consequences to native aquatic invertebrates, some of them endemic (Hughes & Malmqvist 2005). In mainland Portugal, the impacts have probably been the greatest in the most invaded watersheds (Douro, Tejo and Guadiana), where water developments also caused major changes in freshwater habitats. The present results showed that the Mira and Lima drainages are the least invaded and deserve special protection for their native fauna, to prevent future invasions.

The non-native fish establishment rate in Portugal was high (58%) and mirrored establishment rates in other European countries (63%, García-Berthou *et al.* 2005) and worldwide (64%, Ruesink 2005). Both of these values are high when compared with the tens-rule which predicts that only 10% (ranging from 5% to 20%) of species introduced will become established (Williamson & Brown 1986; but see also García-Berthou *et al.* 2005; Jeschke & Strayer 2005; Ruesink 2005). Although the present proportion is similar to other studies, it is probably overestimated because of unreported, failed introductions and the use of highly successful non-natives by humans causing a bias towards success (Moyle & Marchetti 2006; Ribeiro *et al.* 2008).

**Table 2.** Date of detection of each non-native per watershed

| Species (success/total) | Minho | Lima | Cávado | Ave | Douro | Vouga | Mondego | Lis | Western | Tejo | Sado | Mira | Southwest and Algarve | Guadiana | Azores | Madeira |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Anguilla anguilla* (0/?) | | | | | | | | | | | | | | | | |
| *Achondrostoma oligolepis* (0/1) | | | | | | | | | | | | | | | **1879*** | |
| *Alburnus alburnus* (3/3) | | | | | | | | | | 2003 | 2004 | | | **2001** | | |
| *Barbonymus schwanenfeldii* (0/1) | | | | | | | | | | | | | | **2005*** | | |
| *Barbus bocagei* (0/?) | | | | | | | | | | | | | | | | |
| *Carassius auratus* (12/14) | 1988 | 1995 | 2000 | 1989 | 1800 | 1888 | 1884 | 1995 | 1997 | 1932 | 1980 | | 1943* | 1962 | **1792*** | |
| *Ctenopharyngodon idella* (0/1) | | | | | | | | | | **1990*** | | | | | | |
| *Cyprinus carpio* (15/15) | 1892 | 1995 | 1989 | 1990 | **1800** | 1991 | 1983 | 1995 | 1997 | 1865 | 1962 | 1985 | 1943 | 1886 | 1890 | |
| *Gobio lozanoi* (8/9) | 2000 | | 1999 | 1997 | **1925** | 1998 | 1988 | 1995 | | 1979 | | | | 1996* | | |
| *Pseudochondrostoma polylepis* (1/1) | | | | | | | | | | | | | **2002** | | | |
| *Rutilus rutilus* (1/1) | | | | | | | | | | | | | | | **1895** | |
| *Tinca tinca* (5/6) | | | | | **1800** | | 1993 | | 1892* | 1894 | 1995 | | | 1886 | | |
| *Ameiurus melas* (4/4) | | | | | **1999** | | | | | 2000 | 2002 | | | 2001 | | |
| *Silurus glanis* (0/1) | | | | | | | | | | **2000*** | | | | | | |
| *Esox lucius* (5/5) | | | 2000 | | **1950** | | | | | 1979 | | | | 1962 | 1979 | |
| *Oncorhynchus mykiss* (8/8) | 1993 | | 1932 | | **1900** | 1998 | 1988 | | | 1988 | | | | | 1941 | 1960 |
| *Salmo salar* (0/4) | 1898* | 1898* | 1898* | 1898* | | | | | | | | | | | | |
| *Salmo trutta* (0/10) | 1898* | 1898* | 1898* | 1898* | 1898* | 1898* | 1898* | | | 1898* | | | | | 1880* | 1960* |
| *Salvelinus fontinalis* (0/1) | | | | | **1900*** | | | | | | | | | | | |
| *Fundulus heteroclitus* (1/1) | | | | | | | | | | | | | | **1975** | | |
| *Gambusia holbrooki* (11/11) | 1993 | | | | 1950 | **1939** | 1988 | 1998 | 2001 | 1953 | 1952 | 1985 | 1997 | 1985 | | |
| *Lepomis gibbosus* (13/13) | | 1998 | 2001 | 1991 | 1991 | 1998 | 1996 | 1998 | 1991 | 1979 | **1978** | 1985 | 1997 | 1979 | | |
| *Micropterus salmoides* (13/14) | 1988 | | 1988 | 1988 | 1987 | 1981 | 1983 | 1995 | 1991 | 1981 | 1979 | 1985 | 1997 | 1962 | **1898*** | |
| *Perca fluviatilis* (1/1) | | | | | | | | | | | | | | | **1898** | |
| *Sander lucioperca* (5/5) | | | | 1997 | 1999 | | | | | 2005 | | | | 2005 | **1980** | |
| *Australoheros facetus* (3/5) | | | | | | **1940*** | | | | | 1984 | 1985* | 1997 | 1962 | | |
| Successful/total | 6/8 | 3/5 | 7/9 | 6/8 | 11/13 | 7/9 | 8/9 | 6/6 | 5/6 | 12/15 | 9/9 | 4/5 | 6/7 | 12/14 | 6/10 | 1/2 |
| Zoogeographic Index | 0.70 | 0.81 | 0.67 | 0.68 | 0.59 | 0.70 | 0.65 | 0.63 | 0.69 | 0.63 | 0.57 | 0.75 | 0.67 | 0.59 | 0 | 0 |

Years in bold represent the earliest date. Zoogeographic Index and number of successful non-native species per total number of species in each watershed are given. See Figure 1 for location of drainages in Portugal; data obtained from Lourenço (2004) and references in Ribeiro *et al.* (2007a).
*Indicates non-establishment.

A surprising finding was that fish species from the same geographic region, the Iberian Peninsula, had a relatively low rate of establishment and success; of the six Iberian non-natives species, only two, *Gobio lozanoi* Doadrio & Madeira and *Pseudochondrostoma polylepis* Steindachner, were successful. Moyle & Marchetti (2006) showed that for California, a region with a similar climatic regime, regional fishes had a high likelihood of establishment once introduced. However, the failed Iberian introductions were performed by the official fisheries authority more than 50 years ago, probably using low numbers of individuals (Lourenço 2004). According to Lockwood, Cassey & Blackburn (2005), the number of individual fish used in an introduction event (propagule pressure) is one of the most important factors determining success of non-native species. In addition, the high morphological similarity between natives of Iberian watersheds reduces the detection of translocated species.

García-Berthou *et al.* (2005) described the predominant pathways of freshwater fish introductions into Europe from North America and within Europe. Later Clavero & García-Berthou (2006) showed greater fish community similarities between Catalonia and French drainages than between Catalonian and other Spanish drainages, demonstrating that new species initially came to central Europe, then colonised Spain and later Portugal (García-Berthou *et al.* 2005; Clavero & García-Berthou 2006). The high number of non-native fishes first detected in the large international drainages (Tagus, Douro and Guadiana, Table 2) supports this pathway. Most species were detected first in Spain and later in Portugal [e.g. *Ameiurus melas* (Rafinesque), Elvira 1984; Gante & Santos 2002; Ribeiro, Chaves, Marques & Moreira da Costa 2006].

The most important reasons for non-native fish introductions into Portugal were for recreational fishing and as ornamental (aquarium) fish. The former was the main reason for introduction and spread in Spain and elsewhere (Elvira & Almodóvar 2001; Cambray 2003; Copp *et al.* 2005b), but at a global level aquaculture seems to be the most important factor (Welcomme 1988). Today, stocking programmes are restricted to planting *Oncorhynchus mykiss* (Walbaum) in some isolated mountain lakes (J. Bochechas, personal communication). Therefore, the recent spread of non-native species to new drainages is solely caused by illegal introductions by anglers. The use of fish for aquaria has contributed to introductions, but the number of failed introductions is underestimated because of low survival of tropical species and/or to the reduced propagule pressure. In Spain, several tropical species such as *Astronotus ocellatus* (Agassiz) and *Pygocentrus nattereri* Kner (Elvira & Almodóvar 2001; B. Elvira, personal communication) were detected but with no evidence of success, and in Portugal the recent occurrence of *B. schwanenfeldii* is further evidence of this pathway (Gante, Moreira da Costa, Micael & Alves 2008). In Britain, ornamental fish introductions have been pointed out as the most frequent cause of establishment (Copp *et al.* 2005a, 2006). For both of these pathways, high frequency of introduction events and numbers of individuals introduced enhance the likelihood of establishment (Sakai, Allendorf, Holt, Lodge, Molofsky, With, Baughman, Cabin, Cohen, Ellstrand, McCauley, O'Neal, Parker, Thompson & Weller 2001; Lockwood *et al.* 2005; Ruesink 2005; Duggan, Rixon & MacIsaac 2006).

### Management measures

Three of the largest Iberian rivers are trans-national with the headwaters located in Spain and the lowlands in Portugal. This highlights that management interventions to stop or reduce the rate of new invasions must be done simultaneously in both countries to be effective. First, there is a need for homogenisation of inland fisheries legislation at the regional, national and international scales, to reflect a consistent policy towards fish introductions, combined with effective law enforcement. Secondly, environmental education focusing on angler associations and aquarists is needed to increase the awareness of environmental and economic consequences of fish introductions. For anglers, this measure could easily be done by implementing a code of practice (see EIFAC 2008) and distributing handouts to call attention to the problems caused by non-native species when fishers request their annual permit. A more proactive action but costly would be to conduct interviews or examinations for fishers that request a fishing permit. Similarly, public awareness should be increased for pet holders to prevent release of ornamental fishes into ponds and rivers, as suggested by Copp *et al.* (2006). This measure should be accompanied by establishing solutions for unwanted fish, such as creating a used-pets trade or involving local zoos to accept unwanted fish.

It is also worth noting that not all watersheds in Portugal were equally invaded. The relatively low frequencies of alien species in the Lima and Mira suggest that these drainages should receive special attention to prevent further invasions and to conserve native fishes. In the Azores and Madeira, where the freshwater ecosystems were originally fishless, it would be worth discovering if any remnant fishless lakes or rivers still exist and if restoration of some waters to a fishless condition would be possible to favour endemic invertebrates and restore the ecosystem function.

Non-native fishes are one of the main challenges to conservationists who wish to protect and manage native fish communities. In Portugal, as well as in other Mediterranean regions, the intensification of reservoir building simultaneously alters riverine ecosystems and aids the establishment of more non-native fishes (Moyle & Light 1996; Collares-Pereira, Cowx, Ribeiro, Rodrigues & Rogado 2000; Clavero *et al.* 2004). Therefore, management actions must be part of a much broader programme for the protection and conservation of the endemic and highly imperiled native fish fauna of Iberian Peninsula.

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