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SPREAD OF THE ALIEN BLEAK *ALBURNUS ALBURNUS* (LINNAEUS, 1758) (ACTINOPTERYGII, CYPRINIDAE) IN THE IBERIAN PENINSULA: THE ROLE OF RESERVOIRS

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ABSTRACT

Since its first record in a tributary of the Ebro basin in 1992, the bleak *Alburnus alburnus* has spread to almost the whole Iberian Peninsula. In this paper (based on electrofishing surveys in 598 localities), we provide information on the expansion of the bleak. We detail current distribution in the Ebro basin and the rivers of the Eastern Pyrenees and we report its presence in three other major Iberian drainages. Currently, the bleak is sympatric with 15 Iberian endemic species (58% of total Iberian endemic fish). The possible threats to the rich Iberian ichthyofauna caused by the presence of the bleak are discussed. The factors that promoted the extremely rapid expansion of this exotic cyprinid are examined, focusing on the role of reservoirs, which seem to favour its dispersal.

Key words: cyprinids, distribution, fish introductions, Iberian Peninsula, invasive species.

RESUMEN

Expansión del alburno *Alburnus alburnus* (Linnaeus, 1758) (Actinopterygii, Cyprinidae) en la península Ibérica: el papel de los embalses

Desde su aparición en un afluente de la cuenca del Ebro en 1992, el alburno *Alburnus alburnus* se ha expandido en gran parte de la península Ibérica. El presente trabajo aporta nueva información sobre su expansión (basada en el muestreo de 598 localidades mediante pesca eléctrica). Se facilita información detallada sobre su actual distribución en la cuenca del Ebro y en cuencas al este de los Pirineos, así como nuevas citas de tres grandes cuencas hidrográficas. De acuerdo a su actual distribución en la península Ibérica, el alburno habita en simpatría con 15 especies endémicas (el 58% del total de

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endemismos ibéricos). Se analiza la posible amenaza que el alburno representa para la ictiofauna ibérica, examinando los factores causantes de su rápida expansión, en especial el papel de los embalses.

Palabras clave: ciprínidos, distribución, introducciones de peces, península Ibérica, especies invasoras.

Introduction

One of the major threats to the freshwater fish fauna stems from the accidental or deliberate introduction of exotic species (Cambray, 2003). This threat is particularly important in the Iberian Peninsula, a major hotspot of European freshwater fish biodiversity, with 74% of primary freshwater fish being endemic (Doadrio, 2001), of which many considered as Critically Endangered in Portugal and/or Spain (Doadrio, 2001; Cabral *et al*., 2005). This valuable Iberian fish fauna is mainly threatened by habitat degradation and uncontrolled introductions of exotic fish.

Over the past decades, the Iberian Peninsula has been subjected to numerous fish introductions mainly for angling purposes, aquaculture, ornament, biological control or accidentally (García-Berthou & Moreno-Amich, 2000; Elvira & Almodóvar, 2001). In Spain, 25 exotic species have become established, representing almost 30% of the Spanish freshwater fish fauna (Elvira & Almodóvar, 2001), while in Portugal 13 exotic species have been reported (Almaça, 1995; Gante & Santos, 2002), with increasing new records in both countries (Caiola & Sostoa, 2002; Benejam *et al*., 2005). Such a scenario requires detailed information on the distribution of exotic species, in order to evaluate likely threats to the native fish fauna and to assess the mechanisms that are promoting this high level of introduction and expansion of exotics. The recent introduction and spread of the bleak might illustrate the speed and extent of the dispersal of exotics in Iberian waters.

The bleak *Alburnus alburnus* (Linnaeus, 1758) is a small cyprinid fish with a wide distribution in Europe, from the east slope of the Pyrenees to the Ural Mountains (Pérez-Bote *et al*., 2004). In 1972, the bleak was accidentally introduced with other fish species from Britain to Cyprus, where it was established and breeding (Lever, 1990). In the Iberian Peninsula the bleak was repeatedly introduced as a forage species by anglers (CHE, 1997; Pérez-Bote *et al*., 2004; Velasco *et al*., 2005). Its introduction was associated with the introduction of major predators such as the northern pike *Esox lucius* (Linnaeus, 1758), the largemouth bass *Micropterus salmoides* (Lacepède, 1802) (Elvira & Almodóvar, 2001), the zander *Sander lucioperca* (Linnaeus, 1758), and the wels catfish *Silurus glanis* (Linnaeus, 1758) (Carol *et al*., 2003). In June 1992, the bleak was collected for the first time in the River Noguera Ribagorzana, a tributary of the Ebro basin, where it became established (Elvira, 1995). Four years later, it was also collected in five rivers of this basin (Cinca, Segre, Jalón, Guadalope and Matarranya) (CHE, 1997). In 1997 it was recorded for the first time in river basins from the Eastern Pyrenees slope (Muga River, northeastern Spain) (Cardona *et al*., 2002) (Figure 1). Doadrio (2001) documented this expansion in the Ebro basin and in Mediterranean Rivers from eastern Spain (Júcar, Turia and Mijares). Around 1999 the bleak appeared in two other major Iberian basins: the Douro in the north (Tormes River) (Velasco *et al.* 2005) and the Guadiana in the south (Campo Maior reservoir, Portugal), extending its range to the Spanish border (Pérez-Bote *et al*., 2004). According to Carol *et al*. (2003), in 2003 the bleak was also introduced into several reservoirs located on three basins of the Eastern Pyrenees (Foix, Llobregat and Ter; Figure 1). More recently, the bleak was recorded from three reservoirs of the Douro basin (Velasco *et al*., 2005), in the Segura basin (southeastern Spain; Andreu-Soler *et al*., 2004) and in two additional reservoirs in the Guadiana basin in Spain (Pérez-Bote *et al*., 2004).

The aim of this work is to describe and map current distribution of the bleak in the Iberian Peninsula with several new records. We also analyse the likely threats of the presence of the bleak in Iberian waters to the rich endemic fish fauna. The factors that promoted the extremely rapid expansion of this exotic cyprinid are examined, focusing on the role of reservoirs, which could favour the dispersal of the species. Considering that reservoirs modify the flow regime, we expect a different occurrence pattern: downstream of dams the bleak should show a random distribution whereas upstream it should not be distributed randomly, with a high occurrence close to the dam.

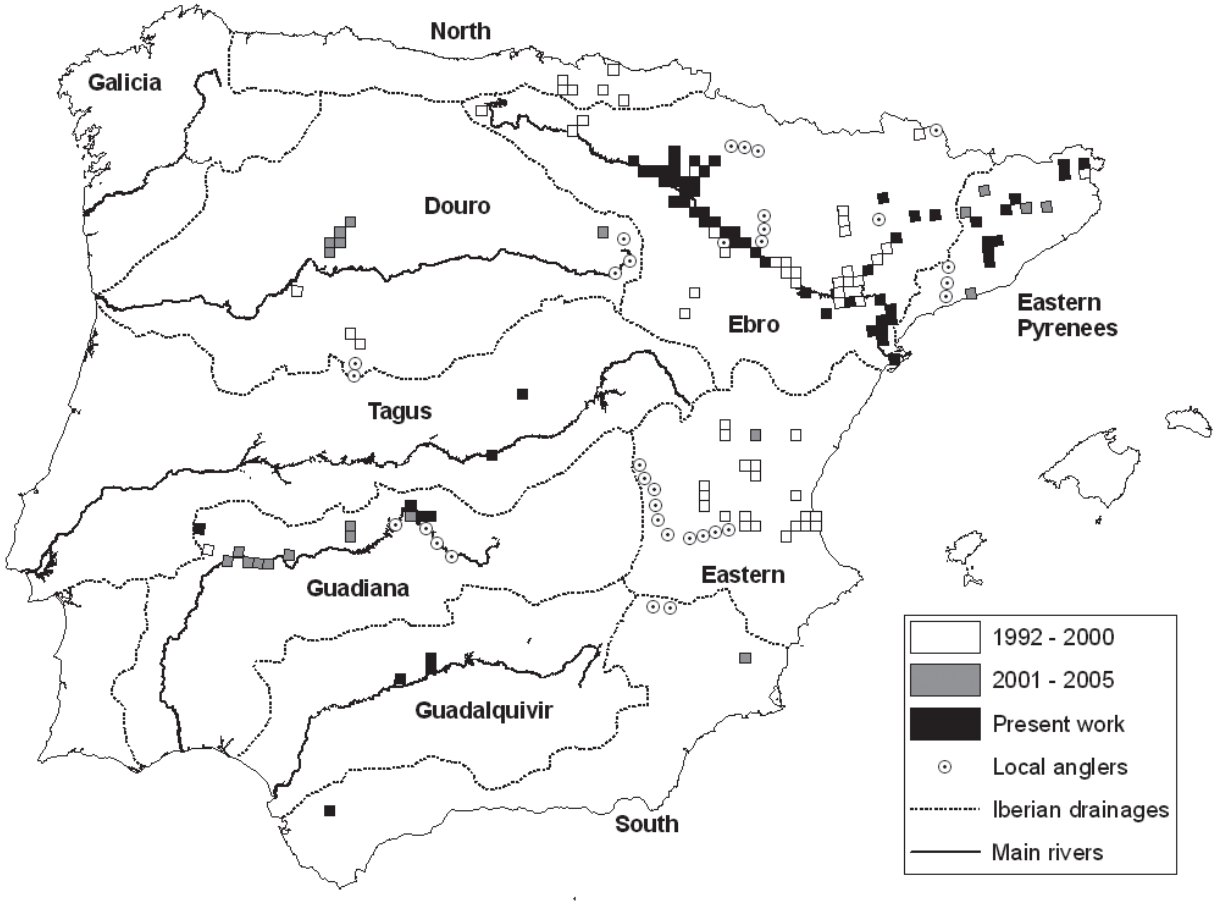

Fig. 1.— Current distribution of the bleak in Iberian basins according to published results (see the methods section for more details), data from the present work (species distribution from 2001 to 2006) and additional information from local anglers.

Fig. 1.— Distribución actual del Alburno en las cuencas ibéricas según resultados que ya han sido publicados (ver apartado de métodos para más detalles), datos del presente trabajo (distribución de la especie del 2001 al 2006) e información adicional facilitada por pescadores locales.

Methods

A total of 598 localities were surveyed by electrofishing between 2001 and 2006: Eastern Pyrenees (N= 222), Ebro (N= 273), Tagus (N= 4), Guadiana (N= 9) and Guadalquivir drainages (N= 90). Two types of data are provided. In the Ebro basin and the Eastern Pyrenees basins regular surveys were conducted, and provided a detailed monitoring of bleak expansion. In other drainages, the surveys were irregular and in several cases the bleak was collected unexpectedly when searching for other species.

Electrofishing was mostly carried out using portable equipment with a current ranging from 300-800 V. In the regularly surveyed area, river sections ranging from 50 to 200 m were sampled, representing the different mesohabitats and usually exceeding an area of 100 m^2. All fish collected were identified and returned alive to the river.

All published information was also surveyed, as well as information provided by anglers, whenever it was considered accurate. However, information from anglers was not used in the statistical analysis and was treated separately, due to the risk of misidentifications.

The information was recorded in digital maps (UTM 10 x 10 km) with ArcView software. Three temporal phases of bleak expansion were mapped:

a) 1992-2000 (CHE, 1997; Doadrio, 2001; Cardona *et al*., 2002; Pérez-Bote *et al*., 2004 and Velasco *et al*., 2005);

b) 2001-2005 (Carol *et al*., 2003; Andreu-Soler *et al*., 2004 ; Pérez-Bote *et al*., 2004 and Velasco *et al*., 2005);

c) 2001-2006 (data from the present work).

To test the hypothesis that reservoirs promote the dispersal of the bleak the distance (≤ 50 km) between locations where the bleak was found and the nearest dam was recorded. The position of the dam (upstream or downstream of the bleak site) was also recorded. In three cases where bleak sites were located between two dams at distances smaller than 50 km, the distance to each dam was recorded separately. Five tests of distribution fitting were performed to determine distribution types. Overall tests showed coincidence, so that only Kolmogorov-Smirnov test values are shown in results.

Results

Data are presented separately for the Eastern Pyrenees and Ebro basins, where regular surveys were conducted, and the less systematic information concerning the spread of the bleak in other Iberian basins.

Spread of the bleak in the Eastern Pyrenees and Ebro

Figure 1 shows that over the study period distribution of the bleak in the surveyed area changed markedly. The more significant changes can be summarized as follows: while in many rivers the bleak initially occurred near dams, it became widespread throught the entire river, invaded new tributaries and in many cases reached the headwaters. For instance, in the Llobregat and Ter rivers the presence of the bleak increased from 8% in 2000 to 42% by the end of 2005. In the Ebro river the bleak was present in 624 km of the 910 km of main course and in 35% of tributaries (Figure 1, Table 1). In the middle watercourse of the Ebro, many young of the year (mean fork length ± SD=33.2 ± 7.9 mm, N=215) were found in August 2005. The size of the individuals in this sample ranged from 18 to 121 mm (furcal lenght).

New records in other Iberian drainages

During our surveys (2001-2006), the bleak was found for the first time in the following drainages (Table 1, Figure 1):

- River Fluvià (Les Caselles, 42º10.8'N 2º47.83'E). The isolated presence in this locality suggests a local introduction.
- River Tagus (Toledo, 39º51.67'N 4º01.57'W) and River Manzanares (a Tagus tributary in Madrid 40º25.1'N 3º42.35'W).
- Two tributaries of the median course of the Guadalquivir basin and a reservoir of the same basin (San Rafael de Navallana reservoir, on the main course of the Guadalquivir).
- Guadalcacín reservoir, on the Guadalete river (South drainages).
- River Caia (a small tributary of the Guadiana basin). It is important to note that the ten bleaks captured in this location ranged from 30 to 150 mm (standard length), with four fish being young of the year. Since it is unlikely that small juveniles were introduced by anglers this size variation strongly suggests that the bleak is currently breeding in this river. The species has also been caught in the River Guadiana, close to the mouth of the Caia (Fluviatilis, 2003).

Additional information obtained from anglers

According to information obtained from anglers during 2006, bleak distribution is actually larger than the one referred to this work for all basins surveyed. This information is shown in Figure 1 and comprises the following water bodies:

- River Gaià (Eastern Pyrenees).
- Aragón and Gállego rivers and Santa Ana reservoir (Ebro basin). Aditionally, there is information that suggests introduction of the bleak to a small mountain lake at an altitude of 1500 m (Estanque de Romedo) with the purpose of feeding the introduced charr *Salvelinus alpinus* (Linnaeus, 1758).
- Headwaters of the River Tormes (Douro basin).
- Headwaters of the River Júcar (Southeastern drainages).
- Guadiana basin: headwaters and García Sola reservoir.
- South drainages: River Mundo and Talave reservoir.

Influence of dams and reservoirs in the spread of bleak

Considering river sections of ≤ 50 km above and below of dams we found that downstream dams bleak occurrence fits a uniform distribution [Kolmogorov-Smirnov test = 0.12, $P > 0.05$; Figure

Table 1.— Number of localities sampled in each river and first year of capture of the bleak in the Eastern Pyrenees (EP), Ebro (E), Tagus (T), Guadiana (GA) and Guadalquivir (GR) basins.

Tabla 1.— Número de localidades muestreadas en cada río y año de captura por primera vez del Alburno en las cuencas al este de los Pirineos (EP), y en las cuencas del Ebro (E), Tajo (T), Guadiana (GA) y Guadalquivir (GR).

Basin	Tributary	Number of localities (UTM 10 x 10 km)	Year
Fluvià (EP)	Fluvià	1	2002
Llobregat (EP)	Llobregat	3	2002
Llobregat (EP)	Cardener	3	2002
Llobregat (EP)	Riera Gavarresa	1	2002
Muga (EP)	Muga	1	2002
Muga (EP)	Llobregat	1	2002
Muga (EP)	Orlina	1	2002
Ter (EP)	Ter	1	2004
Ebro (E)	Ebro	27	2001-2006
Ebro (E)	Mayor	1	2004
Ebro (E)	Ega	1	2003
Ebro (E)	Cidacos	1	2001
Ebro (E)	Aragón	6	2003
Ebro (E)	Aragón (Arga)	4	2003
Ebro (E)	Aragón (Zidacos)	2	2004
Ebro (E)	Alhama	1	2004
Ebro (E)	Guadalope	1	2006
Ebro (E)	Segre	3	2003
Ebro (E)	Segre (N. Ribagorzana)	1	2003
Ebro (E)	Segre (Llobregós)	1	2003
Ebro (E)	Matarranya	1	2003
Ebro (E)	Matarranya (Algars)	1	2003
Ebro (E)	Canaleta	1	2003
Guadiana (GA)	Caia	1	2005
Guadiana (GA)	Estena	1	2003
Guadiana (GA)	Estena (Estenilla)	1	2003
Tagus (T)	Tagus	1	2005
Tagus (T)	Manzanares	1	2006
Guadalquivir (GR)	Guadalmellato (Varas)	1	2006
Guadalquivir (GR)	Guadiato (Cabrilla)	1	2006

2 (a)] while upstream bleak occurrence fits an exponential distribution [Kolmogorov-Smirnov test = 0.15, $P>0.05$; Figure 2 (b)]. The dispersal of bleak upstream of dams (at distances ≥ 10 km) was not limited by a lack of long enough river sections (mean length of river sections upstream of dams ± SD = 56.8 ± 38.6 km).

The cumulative presence of dams also showed a significant effect on bleak dispersal, so that when rivers were not regulated upstream of dams bleak occurred close to them [median (interquartile range) = 5.5 (1.8-8) km], whereas in rivers with additional dams upstream a greater expansion was observed [median (interquartile range = 23.2 (6.2-28.8) km; Mann-Whitney *U*-test: U = 20, n_1=10, n_2=11, $P<0.05$].

Sympatric species

A list of autochthonous fish collected with the bleak is presented in Table 1, as well as the total number of species recorded for each drainage.

Seventy-four per cent (N=26) of autochthonous fish species of the Iberian Peninsula are endemic. In our surveys, the bleak is sympatric with at least 15 endemic species (58%). Of these, 12 have some type of threatened status. For example, *Anaecypris hispanica* (Steindachner, 1866), which is Critically Endangered, has a distribution area that completely overlaps with that of the bleak (Table 2). The majority of remaining species, mostly cyprinids, are classified at least as Vulnerable in Spain and/or Portugal. If one considers the number of endangered endemic species present in all water bodies that

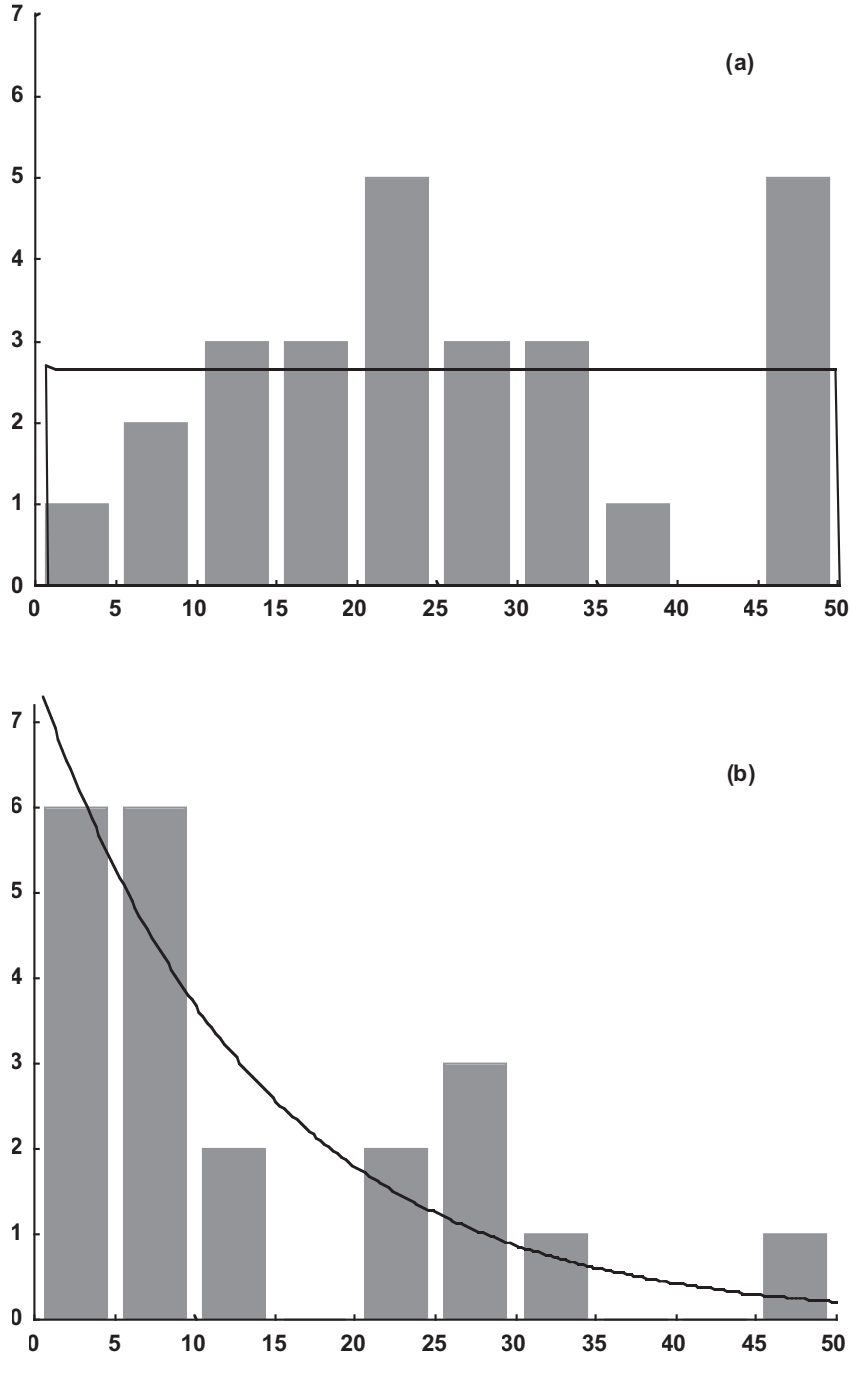

Fig. 2.— Frequency distribution of sites containing bleak near dams (at distance ≤ 50 km) considering intervals of 5 km. The bleak distribution downstream (a) and upstream of dams (b) is shown.

Fig. 2.— Distribución de frecuencias de las localidades con Alburno en función de su proximidad a las presas (a una distancia ≤ 50 km), en intervalos de 5 km. Se muestra la distribución del alburno por debajo (a) y por encima de las presas (b).

Table 2.— List of autochthonous (non-migratory) fish species of the Iberian Península potentially sympatric with the bleak, their current conservation status and number and percentage of basins where the bleak was recorded [(1) Endemic to Portugal, (2) Endemic to Spain, (3) Endemic to the Iberian Peninsula, (4) Endemic to Spain and south France]. * Sympatric species. Conservation status according to the Spanish (Doadrio, 2001) and Portuguese Red Data Books (Cabral *et al*., 2005); categories and criteria follow IUCN (2001). CR = Critically Endangered, EN = Endangered, VU = Vulnerable, LC = Least Concern, NT = Non-Threatened, NE = Not Evaluated. For the former *Chondrostoma* species, we followed the new classification proposed by Robalo *et al*. (2007).

Tabla 2.— Lista de las especies de peces autóctonas (no migradoras) de la península Ibérica potencialmente simpátricas con el Alburno. Se indica su estado actual de conservación, el número y proporción (%) de cuencas en las que se han encontrado junto al Alburno [(1) Endémica de Portugal, (2) Endémica de España, (3) Endémica de la península Ibérica, (4) Endémica de España y del sur de Francia]. * Especies simpátricas. Estado de conservación según los libros rojos de España (Doadrio, 2001) y Portugal (Cabral *et al.*, 2005), siguiendo categorías y criterios de la IUCN (2001). CR = En peligro crítico, EN = En peligro, VU = Vulnerable, LC = Preocupación menor, NT = No amenazado, NE = No evaluado. Para las antiguas especies de *Chondrostoma* se ha seguido la nueva clasificación propuesta por Robalo *et al*. (2007).

Family	**Species**	**Current Status Spain/Portugal**	**Nº of basins**
Petromyzontidae	*Lampetra planeri*	CR/CR	2 (33%)
Salmonidae	*Salmo trutta* *	VU/LC	11 (39%)
Cyprinidae	*Achondrostoma arcasii* * (3)	VU/EN	10 (63%)
	Achondrostoma oligolepis (1)	-/LC	2 (17%)
	Anaecypris hispanica * (3)	EN/CR	1 (100%)
	Barbus bocagei (3)	NT/LC	2 (14%)
	Barbus comizo * (3)	VU/EN	2 (100%)
	Barbus graellsii * (2)	NT/-	6 (75%)
	Barbus guiraonis (2)	VU/-	3 (33%)
	Barbus haasi * (2)	VU/-	5 (45%)
	Barbus meridionalis * (4)	VU/-	3 (50%)
	Barbus microcephalus * (3)	VU/NT	2 (100%)
	Barbus sclateri * (3)	NT/EN	3 (25%)
	Barbus steindachneri (1)	-/NT	2 (100%)
	Gobio lozanoi * (4)	VU/-	12 (75%)
	Iberochondrostoma lemmingii * (3)	VU/EN	4 (80%)
	Iberochondrostoma lusitanicum (1)	-/CR	1 (20%)
	Parachondrostoma arrigonis (2)	EN/-	1 (100%)
	Parachondrostoma miegii * (2)	NT/-	6 (30%)
	Parachondrostoma turiense (2)	EN/-	2 (100%)
	Phoxinus phoxinus *	NT/-	6 (21%)
	Pseudochondrostoma duriense (3)	VU/LC	1 (11%)
	Pseudochondrostoma polylepis (3)	NT/LC	3 (43%)
	Pseudochondrostoma willkommii * (3)	VU/VU	3 (50%)
	Squalius alburnoides * (3)	VU/VU	4 (50%)
	Squalius carolitertii (3)	VU/LC	2 (18%)
	Squalius cephalus *	VU/-	6 (50%)
	Squalius palaciosi (2)	EN/-	1 (25%)
	Squalius pyrenaicus * (3)	VU/EN	7 (26%)
	Tinca tinca	NT/NE	9 (75%)
Cobitidae	*Cobitis calderoni* * (3)	VU/EN	3 (43%)
	Cobitis paludica * (3)	VU/LC	9 (29%)
Balitoridae	*Barbatula barbatula* *	VU/-	4 (57%)
Gasterosteidae	*Gasterosteus gymnurus* *	EN/EN	5 (24%)
Blenniidae	*Salaria fluviatilis* *	EN/EN	4 (67%)

are now starting to be colonized by the bleak, the value rises to 56% for Portugal (two species Critically Endangered, six In Risk of Extinction and two Vulnerable) and to 78% for Spain (four species in Risk of Extinction and 14 Vulnerable) (Table 2). These figures comprise several species from the genera *Parachondrostoma* and *Squalius* (Table 2), namely *P. arrigonis* (Steindachner, 1866) and *P. turiense* (Elvira, 1987), both considered in Risk of Extinction and with an overlap of 100% with bleak distribution (Table 2). Of all endemic species, six have distributions overlaping 100% with that of the bleak (Table 2). Moreover, the bleak co-occurs at least with 12 species of other exotic fish, potentially increasing this pressure on native species.

Discussion

The results of the present work clearly show that the bleak is currently present in all major Iberian basins and is distributed over a large proportion of Iberian rivers. Up to now, only the north and north-west of the Iberian Peninsula seem to be free of the species, although little is known about the current status of the fish fauna in these areas.

What are the causes behind this extremely rapid expansion of the bleak?. New introductions seem to be the result of deliberate actions by anglers that use the bleak either as prey for piscivorous species or as live bait which is frequently released to the water after angling sessions. It is worth keeping in mind that the piscivorous fish are also exotics, which means that anglers are presumably introducing both predators and their prey, thus replacing natural fish assemblages by increasingly artificial ones.

Concerning the rapid spread within rivers where the bleak was already present for some years, it remains unclear to what extent the expansion results from persistent introductions into new localities or from successful breeding and dispersal. However, a breeding population in the Iberian Peninsula is described by Carbonero *et al*. (2006) in the River Tormes. The finding of juveniles in the Ebro and Guadiana rivers in the present work strongly suggests the successful establishment of breeding populations. Thus, the mean size of the small specimens recorded in the Ebro and Guadiana rivers were similar to those described by Carbonero *et al*. (2006) for young of the year in the River Tormes.

In Cyprus, its high fecundity allowed the bleak to outcompete other species (Welcomme, 1988). According to J. Carbonero (pers. comm., 2006) the same situation exists in Iberian rivers. Other factors that may contribute to the adaptability of the bleak include its ability to exploit a widespread spectrum of prey (Vollestad, 1985; Chappaz *et al*., 1987; Biro & Musko, 1995; Vasek & Kubecka, 2004; Mehner *et al*., 2005) and its temperature tolerance (from mountain lakes to the River Ebro with summer temperatures around 30ºC).

In the Iberian rivers of Mediterranean type water regulation, dam construction and excessive water extraction have contributed to a progressive substitution of rheophilic habitats by more lentic ones, and alterations have occurred simultaneously with bleak expansion (Copp, 1990; Elvira *et al*., 1998). In this study a relationship between expansion of the bleak and the construction of dams has been found. Thus, our findings suggest that the species dispersal is more significant in regulated rivers. In non-regulated rivers upstream of dams, the majority of the bleak were located in close proximity to dams (or just in the reservoirs), suggesting that they play an important role in bleak expansion. In its original distribution area the bleak occupies habitats with slow water (Brabrand, 1983). The attenuation of natural flow fluctuations in water bodies caused by dams has already been associated with the presence of other introduced species (Bernardo *et al*., 2003; Clavero *et al*., 2004).

The negative effects of invasive fish species on native fish, communities and ecosystems is widely recognized (Cambray, 2003; Mills *et al*., 2004). The impact of an invader like the bleak needs to be assessed at different levels: genetic pool (hybridization), individuals (changes in life history and behaviour), populations (changes in abundance and distribution of native fish species) and communities (competition, species richness, diversity and trophic structure).

Given the high level of endemics and the large number of critically endangered cyprinids, all factors that can potentially threaten the Iberian freshwater fish fauna need to be carefully monitored. In the case of the bleak two major issues are of special concern: its potential to outcompete native fish due to its very high reproductive output, and specially the potential danger stemming from the hybridization of the bleak with native fish. The bleak has proved to hybridise very easily with other cyprinids (Blachuta & Witkowski, 1984; Crivelli & Dupont, 1987), namely with species of *Squalius* (Wheeler, 1978; Witkowski & Blachuta, 1980; Kammerad & Wuestemann, 1989). The bleak is also a very close relative of the critically endangered *Anaecypris his-*

panica (Robalo *et al*., 2006) and with the paternal line of the hybridogenetic *Squalius alburnoides*, which itself resulted from hybridization between *Squalius* and a close relative of the bleak and *Anaecypris* (Robalo *et al*., 2006). Thus, it is very likely that the co-occurrence of the bleak with several of the Iberian endemics will result in a serious introgression of allochthonous genes into the native populations.

The rapid expansion of the bleak and its potential risks for native fish strongly argue for the need of systematic monitoring of those communities where the bleak has been introduced and the consideration of control plans if necessary. Many countries (including Portugal and Spain) have special laws on the introduction of alien species but these are not always obeyed. In the case of the bleak in Portugal and Spain, little can be achieved without the cooperation of anglers and their associations. Thus, strong efforts aimed at compiling adequate information are urgently needed.

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