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Threats to the conservation of biotic integrity in Iberian fluvial ecosystems

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ABSTRACT

Fluvial ecosystems are highly modified by human activity and the species inhabiting them are more imperiled than their aerial or oceanic counterparts. In addition, freshwater biodiversity per surface unit is higher than terrestrial and marine biodiversity. But from a conservation point of view rivers and streams have received less attention than any other natural system. Impacts in water and habitat quality, flow regime and biotic interactions can be considered the main factors responsible for the lack of biotic integrity in Mediterranean rivers. Dams and impoundments alter drastically the physical habitat structure and the ecological functioning of running waters. But at the same time also modify the flow regime. Biotic interactions are deeply altered by introduced invasive species, which are common and proliferate in reservoirs and other artificial lentic habitats. In this paper we have adapted this classification of the main human impacts on fluvial ecosystems to the Iberian situation summarising them in three groups: water pollution, damming, and introduction of invasive species. We discuss their effects on biotic integrity of running waters through some examples from some of our previous works. Pollution is treated in two alternative ways. Quantifying its importance in the drainage network of a large Mediterranean area in southern Spain, as well as analysing its effect on the structure of macroinvertebrate communities and otter (*Lutra lutra*) distribution. Invasive species are widespread in Iberian inland waters. We hereby present the spatial relationship between native fish communities and invasive centrarchids that populate the peninsula. Finally, the damming impacts are considered through the analysis of its role in the spread and establishment of the invasive species. All of them are just a few examples about how alterated is the natural composition and dynamics of Iberian rivers and streams, i.e. its biotic integrity. The challenge for the future lies in the efficient protection of the biodiversity of Iberian freshwaters in the face of increasing pressures on the aquatic resources. But the first step in preserving our rivers is the real recognition of the extent of the problem, particularly among scientists.

Keywords: River conservation, freshwater biodiversity, water pollution, damming impacts, invasive alien species, macroinvertebrates, freshwater fish, *Lutra lutra*.

RESUMEN

Los ecosistemas fluviales están profundamente modificados por la actividad humana y las especies que los habitan están más amenazadas que sus equivalentes aéreos u oceánicos. Además la biodiversidad acuática continental por unidad de superficie es mayor que la terrestre y la marina. Pero, desde un punto de vista conservacionista, los cursos de agua han recibido menos atención que cualquier otro sistema natural. Impactos en la calidad del agua y del hábitat, en el régimen de caudales y en las interacciones bióticas pueden considerarse como los principales responsables de la falta de integridad biótica de los ríos mediterráneos. Los embalses alteran drásticamente la estructura física del hábitat y el funcionamiento ecológico de las aguas corrientes. Y al mismo tiempo modifican el régimen de caudales. Las interacciones bióticas están muy modificadas por la introducción de especies invasoras, muy comunes en embalses y otros hábitats artificiales lénticos. En este trabajo hemos adaptado esta clasificación de los principales impactos humanos sobre las aguas corrientes a la situación particular de la Península Ibérica, resumiéndolos en tres grupos: contaminación de las aguas, represado de los ríos e introducción de especies invasoras. Discutimos sus efectos sobre la integridad biótica de los ecosistemas fluviales a partir de ejemplos obtenidos de algunos de nuestros trabajos previos. La contaminación se aborda de dos modos alternativos. Cuantificando su importancia en la red de drenaje de una gran área geográfica mediterránea del sur de España, así como analizando sus efectos sobre la estructura de las comunidades de macroinvertebrados y la distribución de la nutria (Lutra lutra*). Las especies invasoras están ampliamente distribuidas en las aguas continentales ibéricas. Aquí se presenta la relación espacial existente entre las comunidades de peces nativas y los centrárquidos invasores que pueblan la península. Finalmente, los impactos de la creación de embalses se estudian a partir del análisis de su papel en la diseminación y establecimiento de las especies invasoras. Todos ellos no son más que unos cuantos ejemplos sobre el grado de alteración de la composición y dinámica de los cursos de agua ibéricos, es decir, de su integridad biótica. El reto para el futuro consiste en la protección eficaz de la biodiversidad acuática continental ibérica en el marco de*

unas presiones cada vez mayores sobre los recursos acuáticos. Pero el primer paso para conservar nuestros ríos pasa por el reconocimiento real de la magnitud del problema, especialmente entre la comunidad científica.

***Palabras clave**: conservación de ríos, biodiversidad acuática continental, contaminación fluvial, impacto de los embalses, especies invasoras, macroinvertebrados, peces continentales,* Lutra lutra.

INTRODUCTION

No other ecosystems have been as significantly modified by human activity as rivers and streams have (Allan, 1995; Ward, 1998; Ricciardi & Rassmussen, 1999; Revenga & Mock, 2000; Nilsson *et al*., 2005). For example, the level of threat for dominant terrestrial vertebrates is 11 to 25 %, while the remaining values for groups occurring more frequently or uniquely in freshwater range from 13 to 65 %. More precise data for North America indicates that freshwater animals are much more at risk, 39 to 68 %, than predominantly terrestrial ones, 15 to 17 %. This gives a sense that, globally, freshwater species, mostly running waters inhabitants, are more imperilled than terrestrial ones (McAllister *et al.,* 2001). In addition, freshwater biodiversity on a hectare-for-hectare basis is higher than terrestrial and marine biodiversity (Revenga & Mock, 2000). But in the impending biodiversity crisis, most attention has focused on tropical moist forests or ocean conservation. Freshwater systems have received less attention than any other natural system, and rivers and streams perhaps least of all (Allan & Flecker, 1993; Abell, 2002).

Over human history, there has been a continuous increase in the variety of ways and intensity with which humankind has modified the physical, chemical, and biological nature of running waters. In fact, hydraulic infrastructures appear as the most ancient engineering constructions (Matheny, 1976). Habitat degradation, physical alteration from dams and canals, water withdrawals, overharvesting of fish and shellfish, pollution, and the introduction of non-native species have all increased in scale and impact in the last century (Revenga & Mock, 2000; Malmqvist & Rundle, 2002). Lotic systems also have an intimate contact with their basins and so are directly affected by land use alterations. Various transformations of the landscape are probably the most widespread and potent threats to the well being of lotic ecosystems. Draining of flooded areas, timber harvest, grazing of livestock, road building, spread of human settlements, and the intensification of agriculture are some of the principal forces behind changes in land use, with attendant consequences for hydrology, vegetation cover, and terrestrial-aquatic linkages. All these modifications affect the composition, structure and function of freshwater communities, i.e. its biotic integrity (Karr *et al.,* 1986). Biotic integrity is defined as "a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of a natural habitat of the region" (Karr, 1981).

The Iberian Peninsula is not an exception, and since ancient times man has altered the natural composition and dynamics of their rivers and streams (e.g. intensive land uses from prehistoric times, roman dams at Merida, or the roman or arabic water mills spread over many streams in southern Spain).

Human-induced impacts on running waters can be classified in five main groups, attending to their different ecosystem affections: energy source, water quality, habitat quality, flow regime and biotic interactions (Karr *et al.,* 1986). But the environmental stressors that affect stream ecosystems are multiple and interacting. The Iberian running waters are mostly of Mediterranean type and so subjected to high flow variability, both within and between years. The flow in the semiarid Mediterranean area fluctuates between catastrophic flash floods and large periods in which river channels stay almost dry. This singularity has two main consequences on human caused impacts on stream ecosystems: 1) as average flow is low, its dilution capacity tends to be similarly low and the water quality tends to be poorer than in temperate areas (Prenda & Gallardo, 1996; Prat &

Munné, 2000). In addition, still a large part of Iberian wastewaters are not properly treated and a high proportion of the rivers are effluent-derived. 2) Due to the existence of long droughts a great part of the drainage network is subjected to flow regulation (MMA 1998, ICOLD 1998).

Thus, water quality, habitat quality, flow regime, and biotic interactions can be considered the main factors responsible for the lack of biotic integrity in Mediterranean rivers. And in addition, all of them are interrelated. Dams and impoundments drastically alter the physical habitat structure and the ecological functioning of running waters. But at the same time also modify the flow regime. Biotic interactions are deeply altered by introduced invasive species, which are common and proliferate in reservoirs and other artificial lentic habitats (Clavero *et al.,* 2004). In this paper we have adapted this classification of human impacts to the Iberian situation summarising treating impacts in three groups: river pollution, damming, and alien invasive species. All of them have strong consequences on the structure and dynamics of native freshwater communities and, unfortunately, their influence is general and widespread all over the Iberian Peninsula. We will discuss their effects on biotic integrity of running waters through the presentation of some examples from some of our previous works, most of them from southern Spain.

The pollution will be treated in two alternative ways. Firstly trying to quantify the pollution degree of the drainage network of a large Mediterranean area in southern Spain. And secondly, analysing its effect on the structure of macroinvertebrate communities and otter (*Lutra lutra*) distribution (Prenda & Gallardo, 1992; Prenda & Granado, 1996; Prenda *et al.,* 2001). Invasive species are known to eliminate native species (Clavero *et al.,* 2004). However, few attempts have been made to quantify this phenomenon in Iberian inland waters. Here, we present the spatial relationship between invasive centrarchids and native fish communities. Finally, the damming impacts will be considered specifically through its role as a factor that favours fish invasive alien species (Prenda *et al.,* 2002; Clavero *et al.,* 2004).

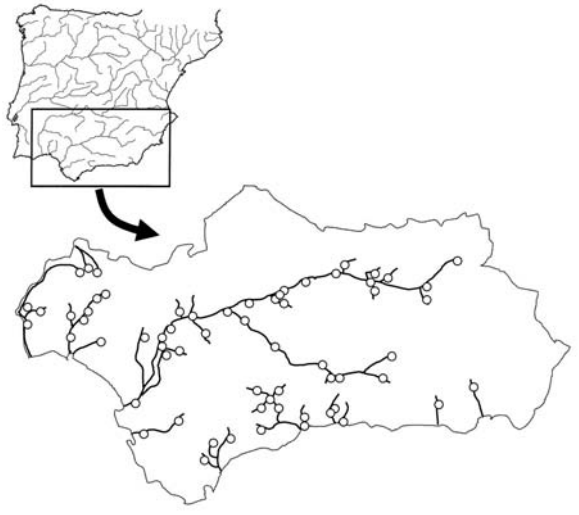

Figure 1. Map of Andalucía (S Spain) indicating the 65 locations (white circles) where the water quality was evaluated. The area encompass a large basin, that of the Guadalquivir, a small part of the lower Guadiana and several minor Mediterranean basins. *Mapa de Andalucía (sur de España) en el que se representan las 65 localidades (puntos blancos) en los que se ha evaluado la calidad del agua. Esta región incluye una gran cuenca hidrográfica, la del río Guadalquivir, una pequeña porción de la del Guadiana y varias cuencas mediterráneas menores.*

RIVER POLLUTION

Stream and rivers are essential components of landscapes and reflect the general condition of the territories where they flow through (Hynes, 1975; Allan, 2004). Consequently, their degree of pollution over large areas can be interpreted as a global indicator of the environmental health of the drained territories. To make a general assessment of Andalucia's inland water pollution and to globally estimate the environmental health of this large territory of southern Spain, the average water quality of 65 sampling stations was computed (Fig. 1). Most of the environmental variability of the area was covered, including a large altitude range, different geologies, types of human settlement, and land uses. The water quality was evaluated through a physico-chemical index (ICG) (Mingo, 1981). The ICG results from the balanced sum of nine basic variables (BOD_5, COD, dissolved oxygen, suspended solids, pH, conductivity, total coli-

forms, total phosphorous and nitrate), and 14 complementary parameters (chloride, sulphate, calcium, magnesium, sodium, detergents, cyanide, phenols, cadmium, chromium, mercury, lead, and zinc). This index is used by the Spanish water authorities to determine the water potential for human uses. It varies between 0 and 100 and is grouped in five categories: 0-60, *inadmissible* (the water cannot have any use); 60-70, *admissible* (some uses are permitted, but with restrictions); 70-80, *fair*, 80-90, *good*; 90-100: *excellent* water. The ICG was analysed for the period January 1995-August 1999 using published data from the Spanish water Authorities (URL: http://www.juntadeandalucia.es/medioambiente/indice_ima.html).

The global average value for the ICG for the period 1995-1999 was 62.9 (range 30.7-89.6), hardly higher than the *inadmissible* level. Half of the 65 sampling stations (33) had an *inadmissible* mean quality (Fig. 2), 12 stations (30 %) were *fair* or *admissible* and only 12 (19 %) reached the level *good*. No one station could be considered as *excellent*.

To avoid the human biased interpretation of water quality derived from the IGC, an independent analysis was carried out on a complete data set including up to 25 physico-chemical and microbiological water quality parameters. The results of a Principal Component Analysis (PCA) ordered the sampling stations along a pollution gradient, that was highly correlated with the ICG (r^2=0.57, p<0.0001, n=56). Thus, not only from a human perspective, but also from an ecological point of view, the water quality of most sampling stations was very degraded.

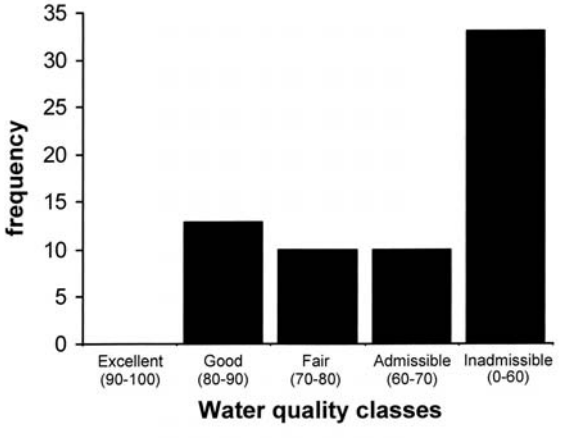

Figure 2. Frequency distribution of the five water quality classes established by the index of water quality, the ICG, for the 65 sampling stations belonging to the Red ICA in Andalusia (January 1995-August 1999). *Distribución de frecuencias de las cinco clases de calidad establecidas por el Índice de Calidad General (ICG) para las 65 estaciones de muestreo pertenecientes a la Red ICA en Andalucía (enero 1995-agosto 1999).*

There is no general data to test the global impact of this highly polluted situation on the freshwater biota, but it must be undoubtedly very important. For example, local studies have shown strong relationships between pollution and the structure of macroinvertebrate communities (Prenda & Gallardo, 1992 1996; Gallardo *et al.,* 1998), fish communities (Vila-Gispert *et al*., 2002), or otter (*Lutra lutra*) distribution (Prenda & Granado, 1996; Prenda *et al.,* 2001).

Between January and May 1987, the spatial and temporal changes in water quality and in the macroinvertebrate community were investigated in the Guadaira basin, a Mediterranean affluent of the Guadalquivir river, chronically exposed to domestic and industrial sewage effluents. Organic pollution levels in this basin were extremely high (mean values ± SE, n=28; permanganate value: 41.0 ± 8.1 mg l^{-1}, dissolved oxygen: 7.2 ± 8.1 mg l^{-1}, sulphide: 7.2 ± 8.1 mg l^{-1}, ammonia: 849.6 ± 291.0 mg-at l^{-1}, phosphate: 70.8 ± 222.6 mg-at l^{-1}). Also, the macroinvertebrate community was greatly impoverished in comparison with other nearby basins. To test the water quality impact on the biota, a pollution gradient obtained after a PCA made on a matrix physico-chemical parameters x sites, was correlated against several macroinvertebrate community indexes (Figure 3). Macroinvertebrate relative abundance, taxonomic richness, and the Shannon diversity index, all significantly decreased with organic pollution. (Prenda & Gallardo, 1996). There was also a strong correlation between the pollution level and the temporal variability in physico-chemical conditions, which at the same time was also negatively correlated with macroinvertebrate community indices. Thus, the biota not only was negatively affected

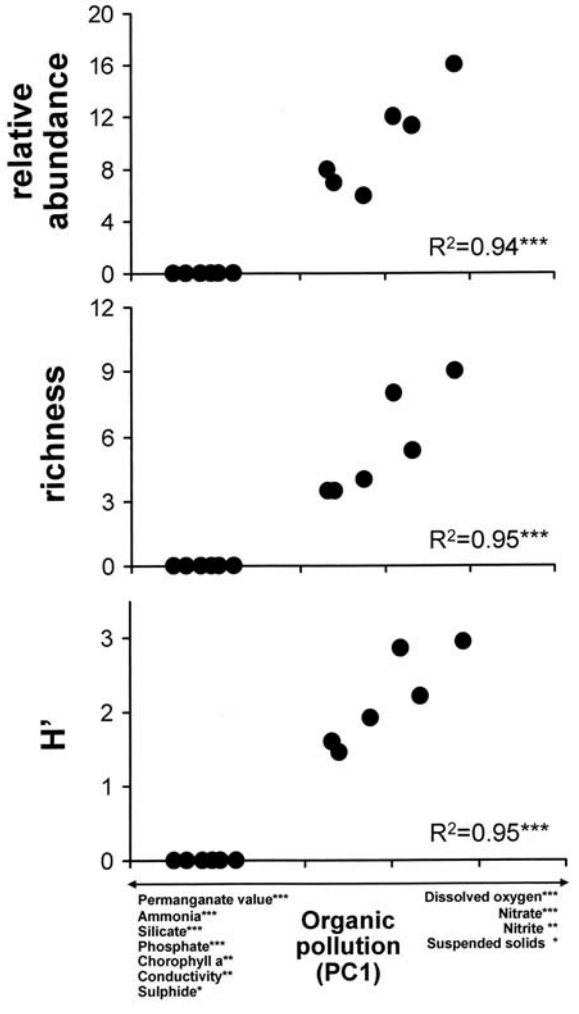

Figure 3. The organic pollution drastically modifies the structure of macroinvertebrate communities in Mediterranean streams. The pollution gradient (PC1) was established after a Principal Component Analysis (PCA) of a matrix of 12 water physical and chemical variables (alkalinity, sulphide, nitrate, nitrite, ammonia, phosphate, permanganate value, silicate, suspended solids, chlorophyll "a", conductivity, and dissolved oxygen) measured in 12 sites in the Guadaira basin (SW Spain). Below the axis the variables significantly correlated with the PC1 are indicated. *** p<0.001, ** p<0.01, * p<0.05. *La contaminación orgánica modifica drásticamente la estructura de las comunidades de macroinvertebrados en ríos mediterráneos. El gradiente de contaminación (PC1) se obtuvo a partir del Análisis de Componentes Principales (ACP) de una matriz de 12 variables físicas y químicas (alcalinidad, sulfuros, nitratos, nitritos, amonio, fosfato, oxidabilidad al permanganato, silicatos, sólidos en suspensión, clorofila "a", conductividad y concentración de oxígeno disuelto) medidas en 12 localidades de la cuenca del Guadaira (SO España). Debajo del eje x se indican las variables significativamente correlacionadas con el PC1. *** p<0.001, ** p<0.01, * p<0.05.*

by the absolute values reached by the physico-chemical parameters, but also by its variance. Water quality and the macroinvertebrate community only benefited from the dilution caused by rainfall (Prenda & Gallardo, 1996).

But this dilution effect in the Mediterranean area is highly variable. Water availability suffers from periodic deficits, both annually (mostly during the summer) and inter-annually, that influence its physico-chemical characteristics. To test if these shifts in water quality/availability were related not only to in-stream aquatic communities but to an aerial predator such as the otter, we compared the distribution of this mustelid between years with different rainfall (Prenda *et al.,* 2001). A total of 561 sites, located in 132 distinct water bodies (103 streams, 24 reservoirs, one irrigation channel and four ponds), were surveyed four times between 1984 and 1995 in the Cordoba province (S Spain) searching for otter signs (mostly scats and footprints). Each survey site had a minimum length of 200 m (even if otter signs where found immediately) and a maximum of 600 m.

An inverse relationship was observed for water pollution and the extension of otter presence in the Córdoba province (r^2=70.3, p=0.09), while this parameter was positively related to water balance, an indicator of water availability (r^2=88.6, p=0.05) (Fig. 4). In fact the reduction in water availability determines a parallel reduction in water quality and the interaction of both factors influence the potential distribution range of otters. Vila-Gispert *et al*. (2002) observed that overall, fish abundance and biomass tended to decrease with pollution in a Mediterranean river in NE Spain. The otter suffer from pollution both directly and indirectly through the depletion of fish -its main prey- availability.

ALIEN SPECIES

Disturbance caused by alien fishes is a worldwide ecological problem that often affects the abundance and distribution patterns of native freshwater fauna, being frequently cited as an important threat to its conservation. The introduction of

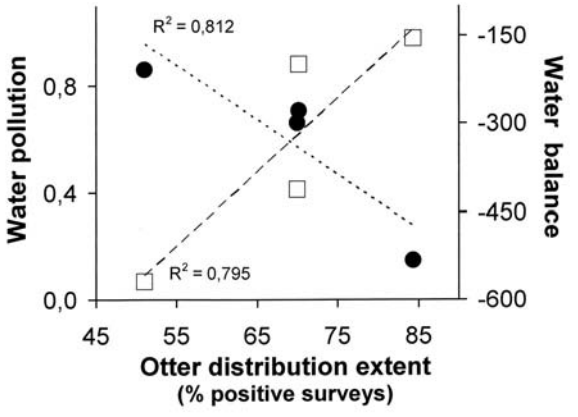

Figure 4. Relationship between the percentage of sites where otter was present in the province of Córdoba (S Spain), the water balance, and the water quality in four periods between 1984 and 1995 (October-December 1984, n=56; July-December 1992, n=261; July 1993-May 1994, n=98; July 1995-February-1996, n= 146). Water pollution degree was visually assigned to one of three categories: nil (more or less transparent water without odours or any other apparent sign indicative of pollution, such as foam); medium-high (water with clear signs of pollution, such as strong odour, turbid colour, foam, etc.); low (sites not assigned to either of the previous categories). *Relación entre el porcentaje de localidades con presencia de nutria en la provincia de Córdoba (S España), el balance hídrico y la calidad del agua en cuatro periodos entre 1984 y 1995 (octubre-diciembre 1984, n=56; julio-diciembre 1992, n=261; julio 1993-mayo 1994, n=98; julio 1995-febrero-1996, n=146). El grado de contaminación del agua fue asignado visualmente a alguna de tres categorías: nulo (aguas más o menos transparente sin olores, ni otro signo aparente de contaminación, como espumas); medio-alto (agua con claros síntomas de contaminación, tales como fuerte olor, elevada turbidez, espumas, etc.); bajo (localidades no asignadas a ninguna de las dos categorías anteriores).*

exotic species is one of the decisive agents causing extinction and is a main responsible besides others of the so-called sixth extinction (Delibes, 2004; Clavero & García-Berthou, 2005). Freshwater ecosystems are ecological islands that contain highly differentiated and isolated species, which are especially sensitive to alocthonous elements. Once an introduced fish species has got acclimated, its eradication results practically impossible and its impact is always negative and unpredictable. This has been called as the Frankenstein effect (Moyle *et al.,* 1987).

There is an impressive record of successful fish invasions that have contributed to the loss of native fish species (Taylor *et al.,* 1984; Di Castri, 1991; Courtenay, 1993; Lever, 1996). The invasion by introduced fishes is a generalised phenomenon in Iberian rivers. At least 25 exotic fish species inhabit inland waters of the Iberian Peninsula (40 % of total resident freshwater fishes), which contains 28 endemic species (Doadrio, 2001). Although the precise mechanisms involved in the interactions between native and exotics are not well known, the alien species are undoubtedly one of the main threats to native fish. García-Berthou and Moreno-Amich (2000) relate the introduction of different fish species along the XX century in the Banyolas lake (NE Spain) with the local extinction of several native species. Aparicio *et al.* (2001) observed in some basins in NE Spain an increase in exotic fish species parallel to a reduction in the native ones.

We collected data on the distribution of fish species in 25 independent river basins in central and southern Iberian Peninsula to check for the importance of exotics (Clavero *et al.* 2004). A mean of 32.4 % of the fish species present in the studied basin had an allocthonous origin, while in the five largest basins (Tajo, Júcar, Guadiana, Segura and Guadalquivir), the proportion rose to 52 %.

One of the most widespread alien species' group in Iberian freshwaters are the centrarchids. This is a fish family endemic to North America with two Iberian representative species, pumpkinseed sunfish (*Lepomis gibbosus*) and largemouth bass (*Micropterus salmoides*). The global impacts of centrarchids on native fish fauna remain largely unknown, but they can be assumed to be very strong. In fact, largemouth bass is considered to be one of the 100 worst invasive species by the IUCN invasive species specialist group (Lowe *et al.* 2000). The composition of fish communities recorded in 50 river and stream stretches in SW Spain (27 in the Guadiana basin and 23 in the Guadalquivir basin) was studied through principal component analysis (PCA) (Prenda *et al*., 2002). The main gradient in fish community composition (PC1) was strongly and positively related with the abundance of both centrachid species. At the same time PC1 was negatively related with nati-

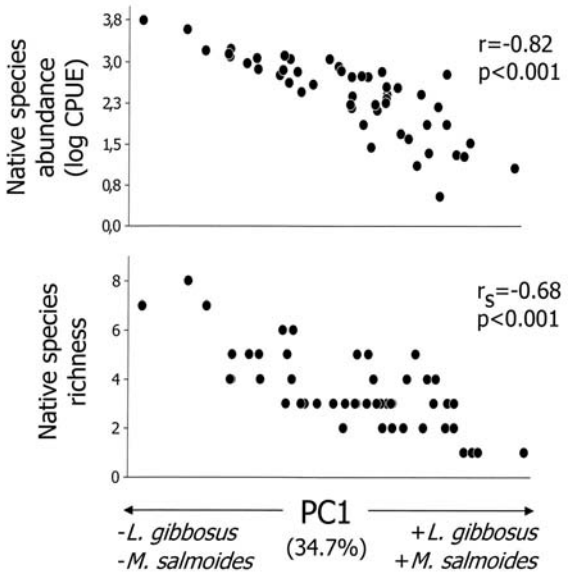

Figure 5. The impact of exotic centrarchids (sunfish+largemouth bass) on native fish communities. PC1 represents a gradient of centrarchid abundance obtained after applying a PCA to a matrix of ten species' abundance (*Barbus* sp., *Cyprinus carpio*, *Chondrostoma lemmingii*, *Ch. willkommii*, *Squalius pyrenaicus*, *S. alburnoides*, *Cobitis paludica*, *Gambusia holbrooki*, *Lepomis gibbosus*, *Micropterus salmoides*) in 50 sites in SW Spain (27 in the Guadiana basin and 23 in the Guadalquivir basin). The percentage of the original variance of the matrix accounted by this gradient appears in brackets. *Impacto de los centrárquidos exóticos (pez sol + blacbás) sobre las comunidades de peces nativos. PC1 representa un gradiente de abundancia de centrárquidos obtenido tras la aplicación de un ACP a una matriz de abundancias de 10 especies de peces (*Barbus *sp.,* Cyprinus carpio, Chondrostoma lemmingii, Ch. willkommii, Squalius pyrenaicus, S. alburnoides, Cobitis paludica, Gambusia holbrooki, Lepomis gibbosus, Micropterus salmoides*) en 50 localidades del SO de España (27 en la cuenca del Guadiana y 23 en la del Guadalquivir). Entre paréntesis se representa el porcentaje de varianza original explicado por este gradiente.*

ve fish abundance and native species richness (Fig. 5). Introduced centrarchids used mostly downstream habitats characterized by high volume and large flows, in which native fish communities should be abundant and species-rich in the absence of alien species. The expected theoretical pattern of native fish distribution in rivers was reversed: their abundance and richness increased upstream. In many river systems, habitat complexity increases as width and depth increase; and fish density, biomass and fish diversity increase in downstream areas (Prenda 1987, Schlosser 1990; Santoul *et al*. 2005).

Moreover, the negative effects of these invasive species are not limited to fish but to other native biota. For example, the otter did not consume this new fish resource as it was available, and usually rejected it (Prenda *et al*. 2002). Thus, the consequences of these fish introductions on river communities are two-fold: 1) the introduced species reduces the total habitat available for the native ones (presumably outcompeting and preying on them); and 2) the new species, at the moment, do not represent and additional food resource for a threatened aquatic predator as the otter. The combination of these two situations could result in a net loss of carrying capacity of the freshwater habitats for native fish and an impoverishment of native communities. Centrarchids can thus be considered a direct short-term threat to Iberian native fish conservation.

DAMMING IMPACTS

Dams have many negative effects on rivers (Revenga & Mock 2000, McAllister *et al.* 2001, Nilsson *et al.* 2005). Unquestionably they cause fundamental changes in community structure and ecosystem function as a naturally free-flowing and continuous river course is transformed into river segments interrupted by impoundments. One of the main biological effects of dams is the obstruction to fish migration and dispersal. The consequences of impoundment on populations of migratory fishes are well known and of serious concern, not only because of the economic value of these fishes, but also for their contribution to regional biodiversity and for their role in the ecology of river and streams (materials flux, biotic interactions, etc.) (Allan 1995). In the Iberian Peninsula several migratory species have become extinct or almost extinct due to river damming. The European sturgeon (*Accipenser sturio*), shads (*Alosa alosa* and *A. Fallax*), sea lamprey (*Petromyzon marinus*) and several mugilid species are nowadays extinct from the Guadalquivir

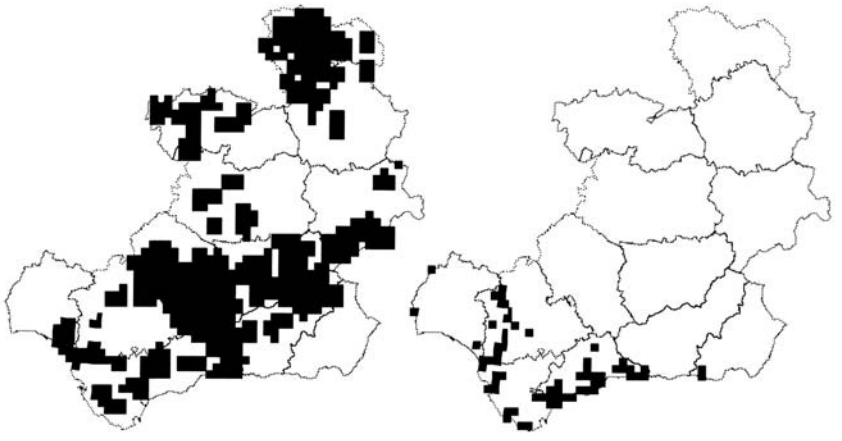

Figure 6. Eel (*Anguilla anguilla*) distribution by the middle of XIX century (from Madoz, 1845-50) and nowadays (from Doadrio 2001) in Andalucía and Castilla-La Mancha autonomous regions (Spain). The Madoz map is just an approach to the probable real distribution of eel. Black points represent 10x10 km UTM squares. *Distribución de la anguila (*Anguilla anguilla*) a mediados del siglo XIX (a partir de Madoz, 1845-50) y en la actualidad (Doadrio 2001) en Andalucía y Castilla-La Mancha (España). El mapa obtenido de Madoz no es más que una aproximación a la distribución probable de la anguila. Los cuadrados negros son cuadrículas UTM de 10x10 km.*

basin because the Alcalá del Río (Sevilla, southern Spain) dam blocks any upstream or downstream fish passage. The eel (*Anguilla anguilla*), a catadromous species, has disappeared from most Iberian inland waters, except from the thin border that remains between the river mouths and the first large obstacle found upstream, usually a dam (Fig. 6) (Prenda *et al.,* 2002). It represents less than the 20 % of its original distribution. These barriers are not only limiting the movement of these species, but their total habitat availability and subsequently their total abundance. The lost of the eel may have had profound consequences in the ecology of Iberian running waters. This species reached high densities –it was usually consumed inland by humans- and was the only true in-stream predator of many Iberian fluvial ecosystems.

It is commonly assumed that introduced species can more easily establish in altered ecosystems such as those created by reservoirs (Herbold and Moyle, 1986; Ross, 1991; Ross *et al.,* 2001). The introduction of fish in reservoirs is an active process: man intentionally spread many fish species for recreational fishing purposes or for other reasons. This represents a new impact, apart from the large physical and biological changes that occur in the new habitat. Most introduced species in Iberian freshwaters originally occupied lentic habitats, which were formerly very scarce in Mediterranean areas (Elvira & Almodovar, 2001). In general, Iberian freshwater fishes are habitat generalists very well adapted to survive in constantly changing

Table 1. Pressing research questions on the research of the biotic integrity in freshwater ecosystems. *Preguntas clave en la investigación sobre la integridad biótica de los ecosistemas acuáticos continentals.*

1. State of the natural system
a) *Distribution of freshwater species and habitats*
b) *Key habitat requirements of focal species*
c) *Characterization of and species adaptation to the natural hydrologic regime*
2. Threats to the system
a) *Gross modifications of aquatic habitats*
b) *Overexploitation of freshwater species*
c) *Introduction of exotic species*
3. Crosscutting planning questions
a) *Economic value of freshwater biodiversity*
b) *Integrating conservation planning across realms*
c) *Incorporating scenarios of global climate change into conservation planning*

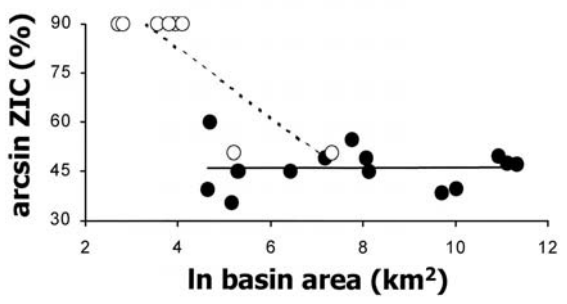

Figure 7. Zoogeographic Integrity Coefficient (ZIC) as a function of basin area. Regression lines are independently represented for dammed (filled circles, solid lines) and non-dammed (empty circles, dotted lines) basins. ZIC is the proportion of autochthonous species among the fish fauna of a certain basin, and can be interpreted as an assessment of the fish community conservation status in each basin. The ZIC values correspond to 25 hydrologically independent basins, including the Tagus, Guadiana, Guadalquivir, Segura, and Júcar and other Andalusian minor basins. *Coeficiente de Integridad Zoogeográfica (ZIC) en función de la superficie de la cuenca. Las líneas de regresión se representan de manera independiente para cuencas con embalses (puntos negros, líneas gruesas) y sin embalses (puntos blancos, líneas a trazos). ZIC representa la proporción de especies autóctonas de la ictiofauna de una cuenca y se puede interpretar como un indicador del grado de conservación de cada cuenca. Los valores del ZIC corresponden a 25 cuencas hidrológicamente independientes, incluyendo la del Tajo, Guadiana, Guadalquivir, Segura y Júcar, así como otras cuencas andaluzas menores.*

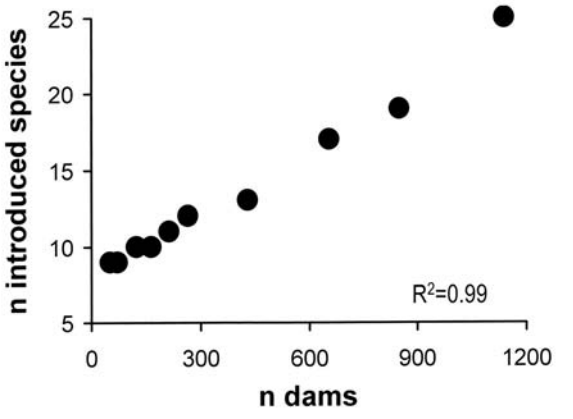

Figure 8. Relationship between the number of dams (source: MMA 1998) and the total number of fish species introduced in Spain (source: Elvira 2001) between 1900 and 2000. *Relación entre el número de embalses (fuente MMA 1998) y el número total de especies de peces introducidas en España (fuente: Elvira 2001) entre 1900 y 2000.*

environments (Magalhães *et al.,* 2002). Reservoirs provide the stable lentic habitats in which introduced species, many of them predatory, can have thriving populations.

An analysis of the fish community composition of 108 reservoirs from southern Spain showed that exotic species were clearly dominant (Prenda *et al.* 2002). Largemouth bass and common carp (*Cyprinus carpio*) inhabited more than 75 % of the reservoirs. Other allochthonous species frequently cited in impoundments were pike (*Esox lucius*) and pumpkinseed. When the mean number of exotic species was compared between reservoirs (n= 108) and free-flowing stream reaches (n= 53), the former had 2.5 times more exotic species than the rivers ($t= 8.4$; $p< 0.0001$) (Prenda *et al.,* 2002).

To evaluate the conservation status of the native fish community in 25 Iberian basins, the proportion of autochthonous species among the fish fauna per basin was assessed. This Zoogeographic Integrity Coefficient index (ZIC) (Elvira 1995b) was dependent on the presence/absence of dams (Fig. 7), but was independent of biotic factors such as native species richness. Once a dam has been established in a basin its conservation value is also independent of its area and the proportion of native species within the fish community is almost constant.

The evidences presented strongly suggest that the patterns of fish community conservation status at basin scale are primarily related to the effects of river damming. It can be therefore suggested that there is a causal relationship in the parallel evolution of the numbers of dams and introduced fish species in Spain during the 20th century (Fig. 8). Spanish rivers feature more than one thousand big dams (at least 1 Hm^3), with its number having experienced a rapid increase since the 1950's (MMA 1998). In spite of this, the National Hydrological Plan projects the construction of around one hundred new dams. In the light of the results shown here, the establishment of new reservoirs is an important threat to native freshwater fish fauna, by promoting the establishment of introduced species, most of which exhibit a high degree of invasiveness in these human created ecosys-

tems. Assuming that conservation of biodiversity is an important assignment, Mediterranean areas' governments should attempt different management strategies of hydrological resources, based on an optimisation of water use.

CONCLUDING REMARKS

Biotic impoverishment includes more than the loss of species. There are many instances where a river contains few or no endangered species and most native taxa still can be located, and yet the biotic integrity has been seriously impaired (Allan & Flecker, 1993). For example, in the Guadalquivir basin (S Spain) there has not been any resident fish species extinction yet, but in the Guadaira river (a left margin tributary of the Guadalquivir, not impounded but heavily polluted) where historical data exist, the fish community has changed drastically from the middle XIX century. Thirty six percent (4 out of 11) of the original community are locally extinct. And the actual fish community contains at least 30 % of exotics (3 out of 10). The remaining native species have declining or almost extinct populations (Prenda, unpublished data). Unfortunately, this short example can be extrapolated to most Iberian running waters. In the Guadalete river (Cádiz province, S Spain) shortly after the building of a big dam, the new reservoir was fully invaded by *M. salmoides* (Ruiz, 1998). The endangered cyprinid *Anaecypris hispanica* was subjected to a declining process that will end with the extinction of this species in the near future (Blanco-Garrido *et al*., 2004). The Guadiana basin where it inhabits has nowadays most its flow regulated by numerous large dams, both in Spain and Portugal.

Summing up all the consequences of river pollution, damming impacts, and generalized introduction of invasive alien species, the native freshwater biodiversity in Iberian inland waters must be severely imperilled. Allan & Flecker (1993) recognise that usually multiple factors play a significant role in species extinctions. If the conservation community acknowledges the freshwater biodiversity crisis, current research fails to reflect it, especially in the Iberian Peninsula. Abell (2002) identifies several of the more pressing things needed in order to conserve world freshwater ecosystems (Table 1), all of them useful for the Iberic situation.

The challenge for the future lies in protecting the ecological integrity and biodiversity of aquatic systems in the face of increasing pressures on freshwater resources (Ward, 1998). But the recognition of the extent of the problem clearly is the first step to responsible stewardship of running waters, particularly among scientists. The situation of freshwater biodiversity is so grave that an urgent action is needed.

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