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ECOLOGY OF AN INVASIVE FISH (*SILURUS GLANIS*) IN CATALAN RESERVOIRS

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Ecology of an invasive fish

(*Silurus glanis*)

in Catalan reservoirs

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Memòria de la tesi doctoral

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Tesi doctoral

Ecology of an invasive fish (*Silurus glanis*) in Catalan reservoirs

Memòria presentada per Joaquim Carol Bruguera
per l'obtenció del títol de Doctor
per la Universitat de Girona

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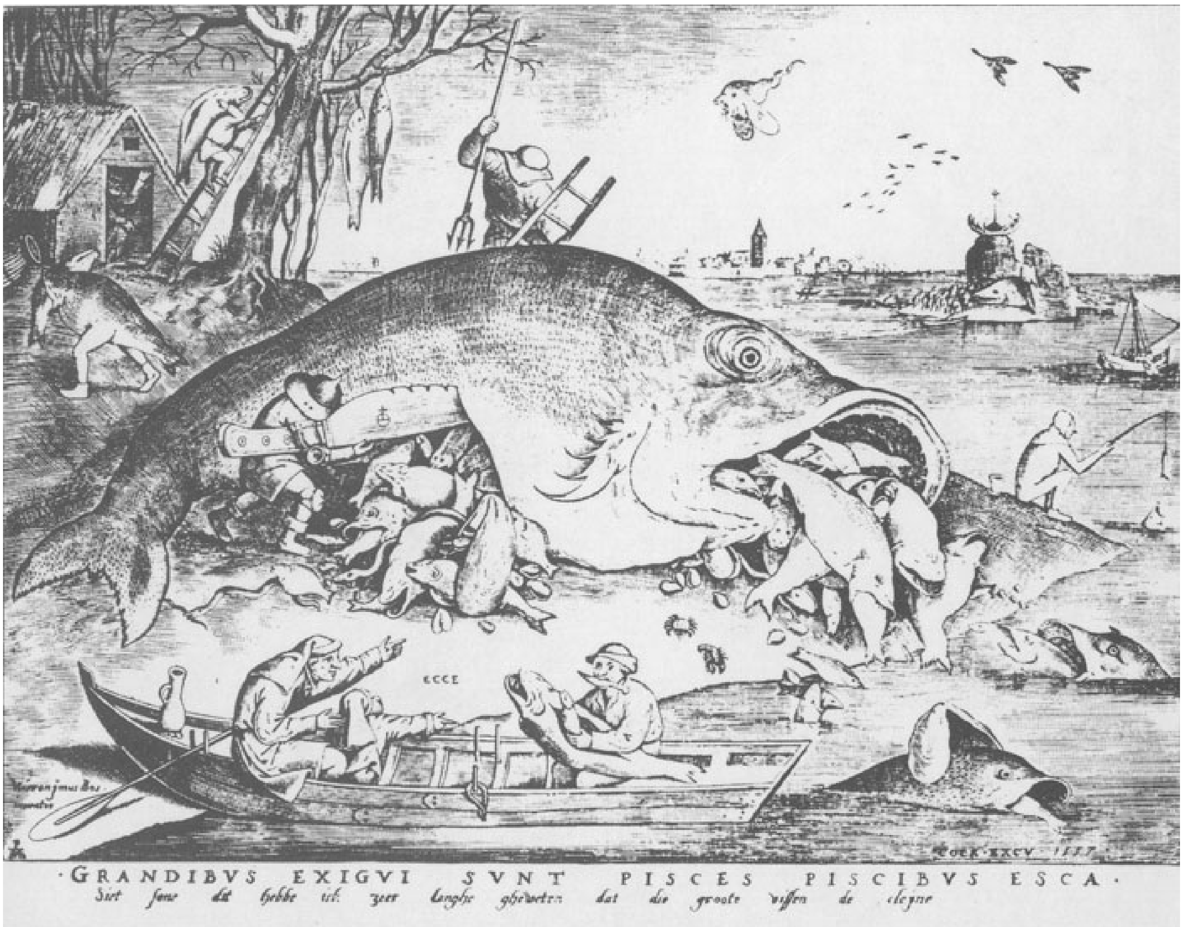
Aquesta tesi doctoral s'emmarca dins els objectius dels projectes de recerca REN2003-00477/GLO del Ministeri de Educació i Ciència i CT02003134 de l'Agència Catalana de l'Aigua. Durant el període de formació pre-doctoral J. Carol ha gaudit d'una beca de recerca de la Universitat de Girona (UdG) (BR 2003-2007).

Per la Laura,

i tots els de casa

“A fish is always the prey of another fish, but the European catfish eats them all” Bohemian proverbe in Gudger, 1945.



****The Big Fish Eat the Small Ones*** (1556) by Peter Brueghel the Elder.

Foto de la portada, Lluís Zamora

Agraïments

Després del DEA arriba una nova oportunitat per fer allò que hauríem de fer més i que cada cop fem menys... agrair. Així, que per tots aquells a qui no ho he dit mai i per alguns que ja els hi dit o que sense dir-ho els hi he fet saber van aquestes quatre línies.

A l'Emili i en Lluís Zamora, moltes gràcies per haver-me donat l'oportunitat de treballar amb vosaltres i amb el grup de peixos, i ensenyar-me aspectes tant diferents d'una bona recerca, per una banda l'anàlisi estadístic i les correccions de les correccions per part de l'Emili i de l'altra el bon fer en al camp, la metodologia de mostreig sempre més complicada del que sembla i de retruc menys agraïda i els bons contactes d'en Zamora. A tots dos, de veritat que moltes gràcies i ja ho sabeu, quan us faci falta un bon "maxaca" aquí el teniu!!!

A la resta de companys de peixos, Carles, Anna, Quim, Luciano, Alejandra, Pablo i Sylvie, Laura Carbó... moltes gràcies pel recolzament tant al camp, laboratori o en algun despatxet. I molt especialment als meus amics i també companys de feina Miguelito, Benito, Sandra (no és de peixos però la poso aquí) i Benejam. Ja sabeu que sense la vostra ajuda això no hagués estat possible i com deia un personatge de Toy Story: *"eternament agraït"* i que tingueu molta sort amb els vostres projectes, segur que coincidim en més d'un.

I com no la gent de l'Àrea i la Facultat que sou molts i de molts grups diferents, merci per les salutacions i xerrades, cafès sense prendre'n al migdia, els dimecres al basc, mogudes amb l'Associació UdG.doc i la penya del cinema i del butlletí, i també a en Narcís de consergeria sobretot per deixar-me les pinces del cotxe tantes i tantes vegades!!!

En el treball de camp un agraïment a la gent de la Reserva Natural de Sebes, el grup de peixos del PN del Delta de l'Ebre, a la família Morilla de Sau tant en Sergi a la presa com la gent de l'allotjament, i molt especialment a en Pepito i la

seva família, pel tracte sempre tant amable i els àpats de campionat que sempre m'he acabat!!!, ja ho sabeu "sóc de vida".

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I per acabar vull donar les gràcies al silur (*Silurus glanis*) i a totes les espècies de peixos natives i no natives que hem capturat. I aprofitar l'ocasió per demanar perdó a les exòtiques per tot el que diem d'elles i considerar-les invasores alhora que ens plantegem eradicar-les i/o regular-les. A les autòctones, demanar disculpes per haver introduït competidors i depredadors en els seu medi malmès i provocar la seva disminució. Així que, ja sabeu, el principal problema de la introducció d'espècies exòtiques som nosaltres i no deixa de ser curiós per no dir-ne llastimós que siguem nosaltres mateixos els que ens creiem capaços de solucionar-ho. Un comportament molt típic dels humans i que els peixos no hi deuen entendre res!!!

Finalment agrair a la gent de Minuartia per donar-me l'oportunitat de treballar amb ells i així iniciar una nova etapa en la meva vida professional i de recerca. Espero que sigui per molts anys!!!

Salut, peixos i somriures!!!

Contents

Summary

SUMMARY

Freshwater ecosystems and reservoirs in particular are especially prone to biological invasions. The aim of this thesis is to provide the first data on the ecology of European Catfish (*Silurus glanis*) introduced to the Iberian Peninsula and to appraise its ecological impact on native biota. We sampled the fish assemblage of 14 Catalan reservoirs (Spain) and analysed its relationship with water quality, finding that altitude and trophic state independently explained most of the variation of fish assemblages. We also modelled the gillnet selectivity for eight fish species and analysed its relationship with fish shape. The European catfish is nowadays introduced in four Iberian river basins: it has been introduced in the Ebro river basin for 30 years, in the Ter and Tajo river basin for a few years and we report the first record for the Llobregat river basin. We demonstrate the utility of comparing early and late invasion stages to understand the ecological changes caused by invasive species: recent introductions of catfish had smaller and younger catfish with growth rates higher than old and native populations and preying on fish instead of crayfish for old introductions. We also report the first published telemetry data for catfish, of an ongoing study aiming at describing activity, mobility and habitat use of catfish.

Resum

RESUM

Els ecosistemes d'aigua dolça i els embassaments en particular són especialment sensibles a les invasions biològiques. L'objectiu d'aquesta tesi és aportar les primeres dades sobre l'ecologia del silur (*Silurus glanis*) introduït a la Península Ibèrica i estimar els seu impacte ecològic sobre la biota nativa. Es van mostrejar les comunitats de peixos de 14 embassaments catalans i s'analitzà la seva relació amb la qualitat de l'aigua, observant que l'altitud i l'estat tròfic explicaven de forma independent la major part de la variació d'aquestes comunitats. També es va modelar la selectivitat de les xarxes de llum variable per vuit espècies de peixos i s'analitzà la seva relació amb la pròpia forma dels peixos. El silur es troba actualment introduït a quatre conques Ibèriques: fou introduït a la conca de l'Ebre fa uns 30 anys, a les conques del Ter i el Tajo fa uns pocs anys i nosaltres l'hem citat per primera vegada a la conca del Llobregat. Hem demostrat la utilitat de comparar estadis d'invasió recents i avançats per tal de mirar d'entendre els canvis ecològics causats per espècies invasores: les introduccions recents presenten silurs més joves, de menor mida i amb taxes de creixement superiors a les de les poblacions introduïdes anteriorment i també respecte les poblacions natives; a més, depreden majoritàriament. sobre peixos, en contra de les poblacions més antigues que s'alimenten sobretot de cranc. Finalment, aportem les primeres dades publicades de telemetria del silur, que formen part d'un estudi més prolongat amb l'objectiu de descriure l'activitat, mobilitat i ús de l'hàbitat del propi silur.

Resumen

RESUMEN

Los ecosistemas de agua dulce y los embalses en particular son especialmente sensibles a las invasiones biológicas. El objetivo de esta tesis es aportar los primeros datos sobre la ecología del siluro (*Silurus glanis*) introducido en la Península Ibérica y estimar su impacto ecológico sobre la biota nativa. Se muestrearon las comunidades de peces de 14 embalses catalanes y se analizó su relación con la calidad del agua, observando que la altitud y el estado trófico explicaban de forma independiente la mayor parte de la variación de estas comunidades. También se modeló la selectividad de las redes de luz variable para ocho especies de peces y se analizó la relación con la forma de estos mismos peces. Actualmente, el siluro se encuentra introducido en 4 cuencas Ibéricas: fue introducido en la cuenca del río Ebro hace unos 30 años, en las cuencas del Ter y del Tajo hace unos pocos años y nosotros lo hemos citado por primera vez en la cuenca del Llobregat. Hemos demostrado la utilidad de comparar estadios de invasión recientes y avanzados para entender los cambios ecológicos causados por especies invasoras: las introducciones recientes presentan siluros más jóvenes, de menor tamaño y con tasas de crecimiento mayores a las de las poblaciones introducidas anteriormente y también en relación a las poblaciones nativas; además, depredan mayoritariamente sobre peces, en contra de las poblaciones más antiguas que se alimentan sobretodo de cangrejo. Finalmente, aportamos los primeros datos publicados de telemetría del siluro, que forman parte de un estudio más amplio con el objetivo de describir la actividad, movilidad y el uso del hábitat del propio siluro.

Introduction

Biological invasions in freshwater ecosystems

After habitat loss, invasive species are the second leading cause of biodiversity decline, particularly in freshwater ecosystems (Moyle *et al.* 1986; Mack *et al.* 2000; Clavero & García-Berthou 2005) and one of the main drivers of global change and biotic homogenization (Rahel 2002; García-Berthou, in press). Biological invasions have caused considerable disruption to native ecosystems throughout the world (Rainbow 1998) through habitat alteration, introduction of diseases or parasites, hybridisation with native species, predation and competition (Taylor *et al.* 1984). Freshwater ecosystems are especially prone to biological invasions, in part because of habitat alteration and degradation (Moyle & Light 1996; Rahel 2002). The impacts of invasive freshwater fish are variable and poorly understood but include some of the most dramatic cases (Drake *et al.* 1989, Moyle & Light 1996) and the Iberian Peninsula is no exception to this (García-Berthou & Moreno-Amich, 2000, Elvira & Almodóvar, 2001). Freshwater fish fauna in the Iberian Peninsula is experiencing a widespread and dynamic invasion process (Clavero & García-Berthou 2006), where at least 28 fish species in 13 families have been successfully introduced into Spanish freshwater ecosystems (Table 1). Thus, 44% of the present freshwater fish species (64 species, excluding the diadromous species) are exotic. The introduction and spread of exotic predatory fish species such as pike, pikeperch, perch, largemouth bass and catfish, and other non-endemic species impact on the survival of native fish species (Elvira 1998). The ecological impact of most of these non-indigenous species is largely unknown with a few exceptions (García-Berthou et al., 2007). Given the high number of introduced fish species and the presence in the Iberian Peninsula of many endemic freshwater fish (Doadrio 2002) the potential impact of these exotic species is enormous and should be urgently investigated.

Table 1. Exotic freshwater fish species introduced to Iberian Peninsula (García-Berthou *et al.*, 2007). * Uncertain establishment

Acipenseridae	*Pseudorasbora parva*	**Poeciliidae**
*Acipenser baerii**	*Rutilus rutilus*	*Gambusia holbrooki*
Salmonidae	*Scardinius erythrophthalmus*	*Poecilia reticulata*
Hucho hucho	**Cobitidae**	**Cyprinodontidae**
*Oncorhynchus kisutch**	*Cobitis bilineata*	*Aphanius fasciatus**
*Oncorhynchus mykiss**	**Ictaluridae**	**Percidae**
Salvelinus fontinalis	*Ameiurus melas*	*Perca fluviatilis*
Cyprinidae	*Ictalurus punctatus**	*Sander lucioperca*
Abramis bjoerkna	**Siluridae**	**Centrarchidae**
Abramis brama	*Silurus glanis*	*Lepomis gibbosus*
Alburnus alburnus	**Esociade**	*Micropterus salmoides*
Carassius auratus	*Esox lucius*	**Cichlidae**
*Ctenopharyngodon idella**	**Fundulidae**	*Herichthys facetum*
Cyprinus carpio	*Fundulus heteroclitus*	

Invasive species are particularly successful in degraded or artificial habitats such as reservoirs. Most streams are nowadays regulated (Ward & Standford, 1979; Petts, 1984), especially in Mediterranean countries, and nearly a half of available water worldwide is retained in more than 800,000 reservoirs (Rosemberg et al., 2000). Reservoirs are of high ecological, economic and recreational importance and are usually built to store water for later use as water supply, flood control, irrigation or power generation (Han et al., 2000). Habitat alteration through reservoir construction may directly cause the extirpation of native species that cannot tolerate the new abiotic conditions (Rahel, 2002). Construction of these artificial reservoirs has been one of the most important interventions to the natural environment and stream fish populations are usually irrecoverably influenced both down- and upstream of the reservoir by changes and homogenization in habitat conditions and by the interruption of migration paths (Hladík, 2005). Most of the lotic species cannot tolerate the lentic conditions and stay close to the shores of the reservoir, the mouth of tributaries and in shallows whereas the pelagic and deep water is poorly used by native species and thus dominated by exotic species (Craig 2000).

The European catfish (*Silurus glanis*)

The introduction of catfish in Catalan reservoirs

The European catfish (*Silurus glanis*) (Fig. 1), also known as wels or sheatfish, is native to eastern Europe and western Asia and most abundant in the Danube and Volga river basins. *S. glanis* is nowadays popular among European anglers and has been introduced and established in many European countries, including Croatia, France, Italy, the Netherlands, Spain, and the United Kingdom (Elvira 2001; Keith & Allardi 2001) for both aquaculture and angling.

Figure 1. The European catfish (*Silurus glanis*).

The European catfish was first introduced to the Iberian Peninsula (Fig. 2) through River Segre (NE Spain) around 1974 apparently (as declared to magazines) by Roland Lorkowsky, a German biologist who illegally introduced 32 young individuals of catfish (Cabistañ 2003). Later, catfish were also introduced in the lower River Ebro at Mequinensa and Riba-roja reservoirs for sport fishing (Elvira & Almodóvar 2001; Doadrio 2002), where it is now abundant and some of the biggest fish in Western Europe reside nowadays in the River Ebro and its tributaries Segre and Cinca. It has also been introduced to a reservoir in the Tajo river basin (2002) and during the development of this thesis we recorded it in 2003 in Susqueda reservoir, Ter river basin (Carol *et al.* 2003) and later on also in Sau reservoir upstream to Susqueda and in La Baells reservoir, Llobregat river basin (see Article III) (Fig. 3).

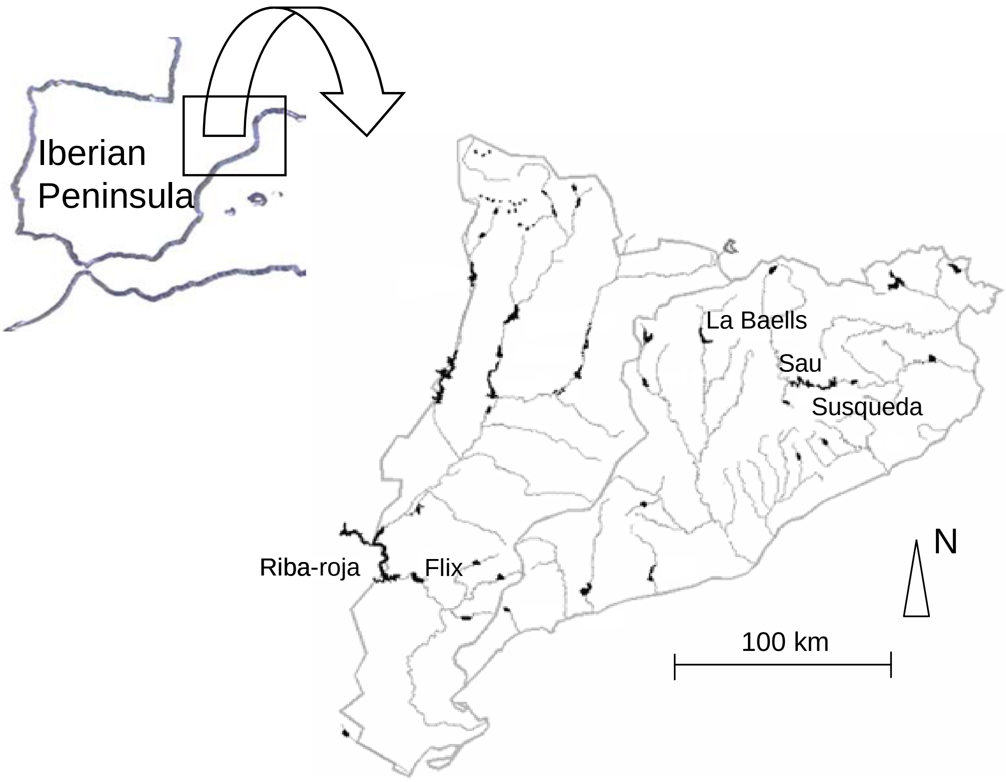

Figure 2. The five Catalan reservoirs with introduced populations of European catfish (Flix, Riba-roja, Sau, Susqueda and La Baells).

Flix Riba-roja

Sau Susqueda

Figure 3. View of the four Catalan reservoirs where European Catfish was studied.

Life history and ecology

The European catfish is a siluriform fish species of the Siluridae family. The catfish is the largest European freshwater fish with a record of 5 m and 306 kg in the river Dnieper (Ukraine) but usually reaching 2.5 m and 100 kg and are found in the lower reaches of large rivers and in muddy lakes (Doadrio, 2002). The body becomes laterally compressed after the head and it is elongated with smooth scaleless skin coated in mucus. It has a broad and flat head, widely spaced nostrils, small eyes and large mouth containing lines of numerous small teeth and two very long, slender and flexible cartilaginous barbs on the upper jaw that working as chemical and sensorial organs, and four short, flexible barbs below the protruding lower jaw (Davies *et al.* 2004). Pigmentation varies according to habitat, but *S. glanis* is generally dark along its back with lighted sides, and white abdomen. Albinism has been reported (Cabistañ, 2003). Nothing is known about life history and ecology of catfish in the Iberian Peninsula and little information is also available in native areas. Maitland (2000) reports that the reproduction of catish is between May and July, spawning 136,000-467,000 eggs per female in shallow water under thick vegetation, where the male excavates a depression in which the eggs are laid by the female and guarded by the male. The larvae hatch in approximately 3 days, measuring around 7 mm, and begin feeding on plankton. Catfish grows quickly and can reach between 1.5 and 4.5 kg in their first year. The young mature after 3-4 years (Alp *et al*. 2004) andmay live up to 25 years (Froese & Pauly, 2007).

The catfish seems to be an opportunistic, aggressive and voracious depredator and it has also been considered as a scavenger rather than predator (Hickley & Chare 2004). Catifsh modifies its diet during ontogeny, consuming invertebrates when young and vertebrates (especially fish and crayfish but also amphibians and waterfowl) when older (Maitland, 2000; Wysujack, 2005). Catfish is a nocturnal predator and during spring it moves to deeper zones and decreases its activity. Catfish has considerable commercial importance in Eastern Europe where it is caught with nets, traps or large baited hooks (Maitland, 2000). It is also produced in a few fish farms for its flesh, skin and eggs for caviar. *S. glanis* is also an increasingly important aquaculture resource in Central and Eastern Europe and most research has been devoted to aquaculture development (Adámek *et al.* 1999; Linhart *et al.* 2002; Alp *et al.* 2004)

Ecological impacts of catfish

The biology and ecology of these naturalized populations of European catfish in Western Europe are poorly known, probably because of the difficulty of sampling such a large species in large rivers or lentic ecosystems (see Article IV). European catfish clearly possesses the attributes of a species well adapted to introductions outside its native range and it is attractive for angling and aquaculture (Copp *et al.*, unpublished ms). Nevertheless, the ecological impact of European catfish on native biota is unknown, although the introduction of some parasites has been noted (Blanc 1997). Due to the enormous size and predatory habits, catfish is potentially a serious risk to abundance and survival of native fish species and other vertebrates (amphibians, birds and small mammals). Catfish might also affect the water quality in reservoirs through trophic cascades.

Structure of the thesis

The general objective of this thesis is to report the first data on the ecology of European catfish in the Iberian Peninsula and to appraise its ecological impact on the native biota, through the study of different populations in Catalan reservoirs (Spain). With this aim, we divided our study in five articles.

In **Article I**, we sampled the fish assemblages of 14 Catalan reservoirs by boat electrofishing in the littoral and multi-mesh gillnets in the limnetic zone. Simultaneously, we assembled eight physical descriptors and we measured 20 water quality features of the reservoirs, and then we analysed the relationship of water quality and fish assemblages. This study also allowed us to detect catfish in several reservoirs and to characterize the fish populations of the several reservoirs where catfish is present.

In **Article II**, from the data of article I we modelled gillnet selectivity for eight freshwater fish species native to many parts of Europe and introduced elsewhere, because knowledge of the size-selectivity of fishing gears is essential to improve estimates of the population structure and size of the fishes caught.

In **Article III**, we report the first record of the European catfish introduced to the Llobregat river basin (NE Spain), namely La Baells reservoir.

In **Article IV**, we present preliminary ultrasonic telemetry data (Fig. 4-10) on the diel movements of European catfish in a Catalan reservoir.

In **Article V**, we study age, growth and diet (Fig. 11) of European catfish in 5 Catalan populations. We used the first pectoral fin ray to age catfish (Fig. 12) and we compared early and late invasions stages of catfish in order to appraise its ecological impact on native biota.

Figure 4. A: Some catfish were captured using an electrofishing boat in both Riba-roja and Flix reservoirs; B & C: Before marking, catfish were measured for mass and total length.

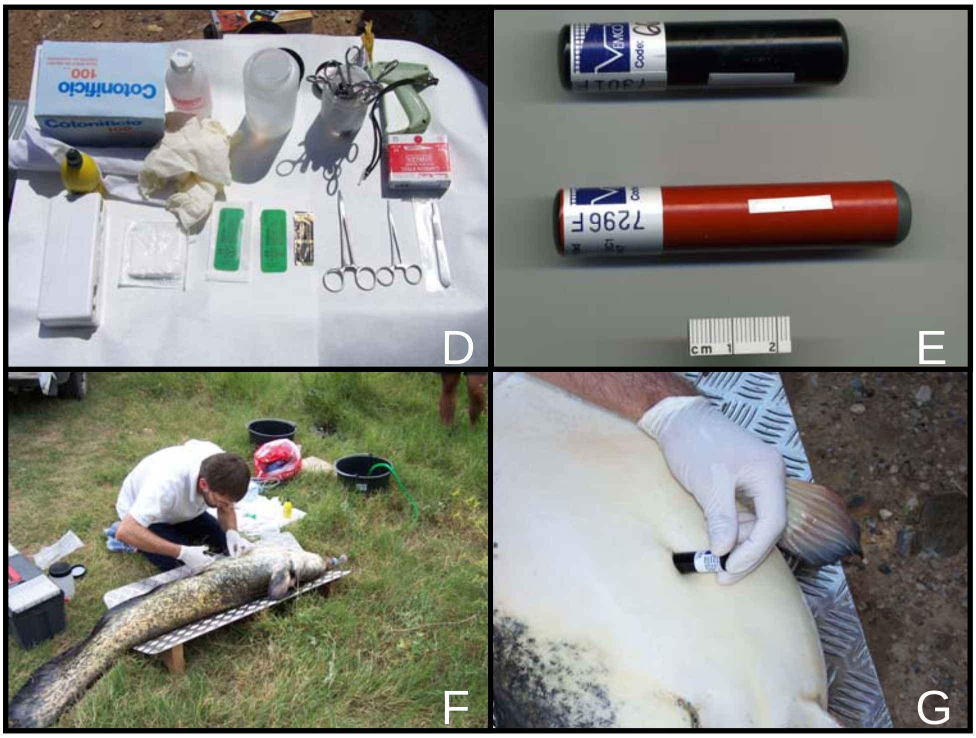

Figure 5. D: Suture kit; E: Ultrasonic tags (V16 and V16P VEMCO) F: Before marking, all catfish were anaesthetized by immersion in MS-222; G: Catfish were tagged by surgical implant into the peritoneal cavity with ultrasonic tags.

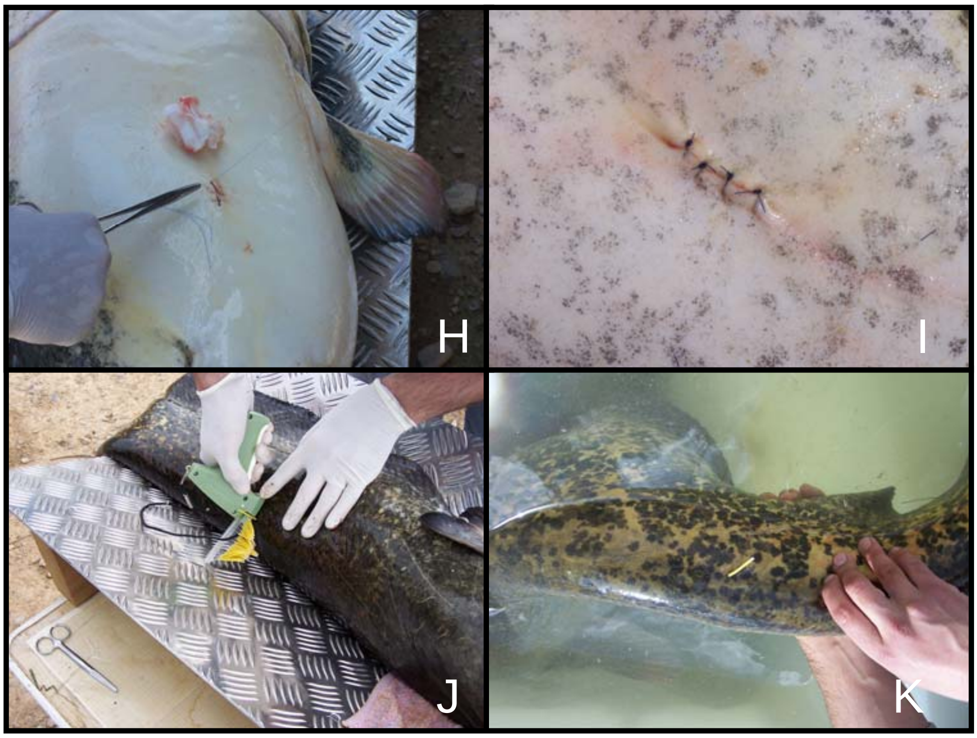

Figure 6. H & I: The incision was closed with 4 separates sutures; J: All the catfish were marked with an external tag to facilitate their identification in future recaptures; K: View of external tag.

Figure 7. L-O: Following suture placement, the fish were transferred to a recovery tank and were released one hour later in their capture place.

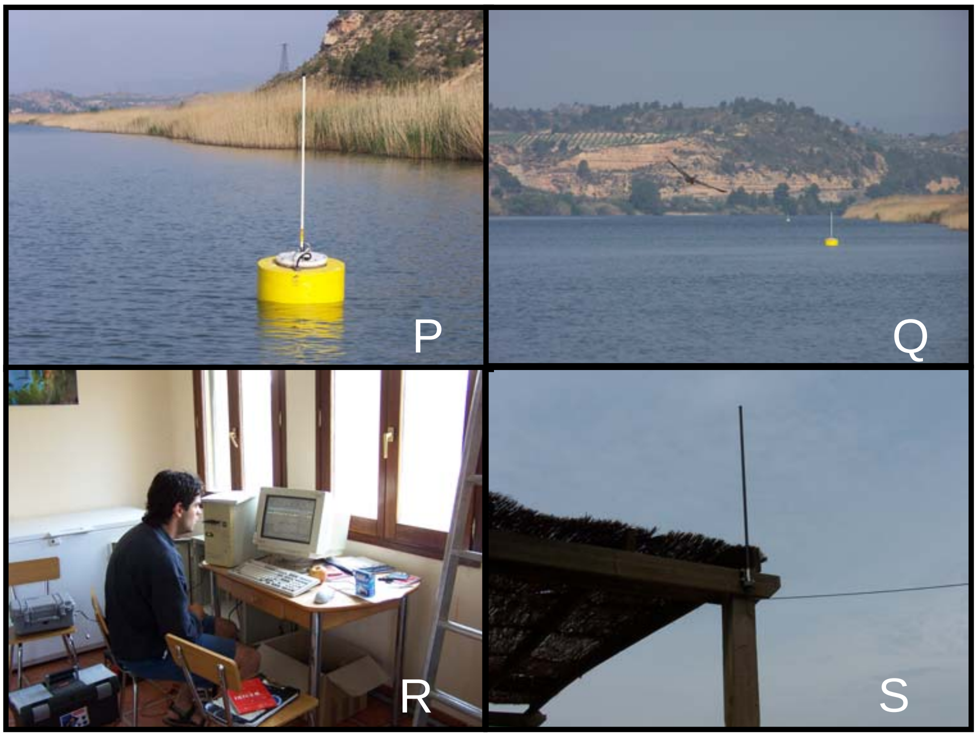

Figure 8. R & S: The buoys were arranged in an approximate 700 m triangle; P & Q: The base station was situated on shore 1 km from the buoys system

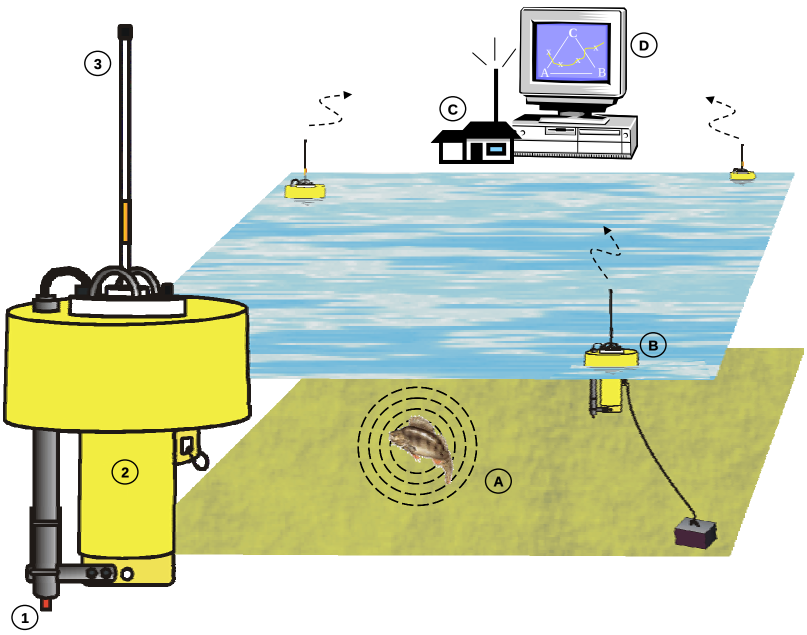

Figure 9. Radio-acoustic positioning and telemetry (VARP, Vemco Ltd.) provides continuous monitoring of fish positions. The system consisted of a computer-controlled base station installed on shore (C), which communicated via VHF radio modems (D) with each of three buoys (B) tightly anchored in the lake. The system measured the time delay when the signal was received at each buoy (A).

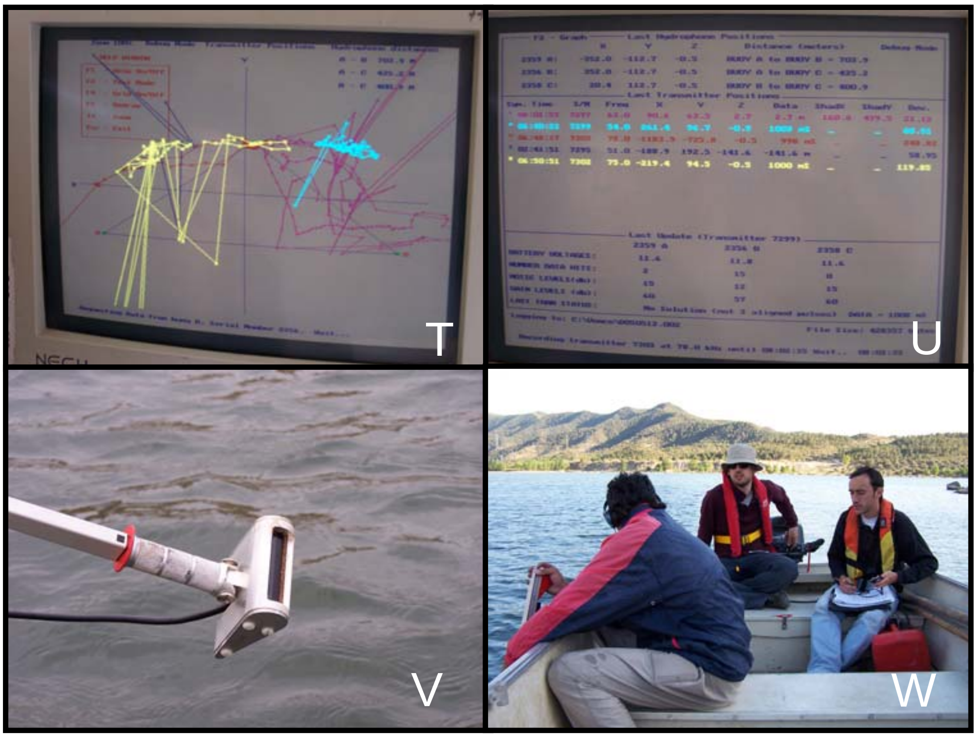

Figure 10. T & U: Individual catfish movements and locations data in base station computer. V& W: manual tracking using a directional hydrophone and acoustic receiver (VR100, VEMCO).

Figure 11. Crayfish in stomach contents of European catfish in Flix reservoir.

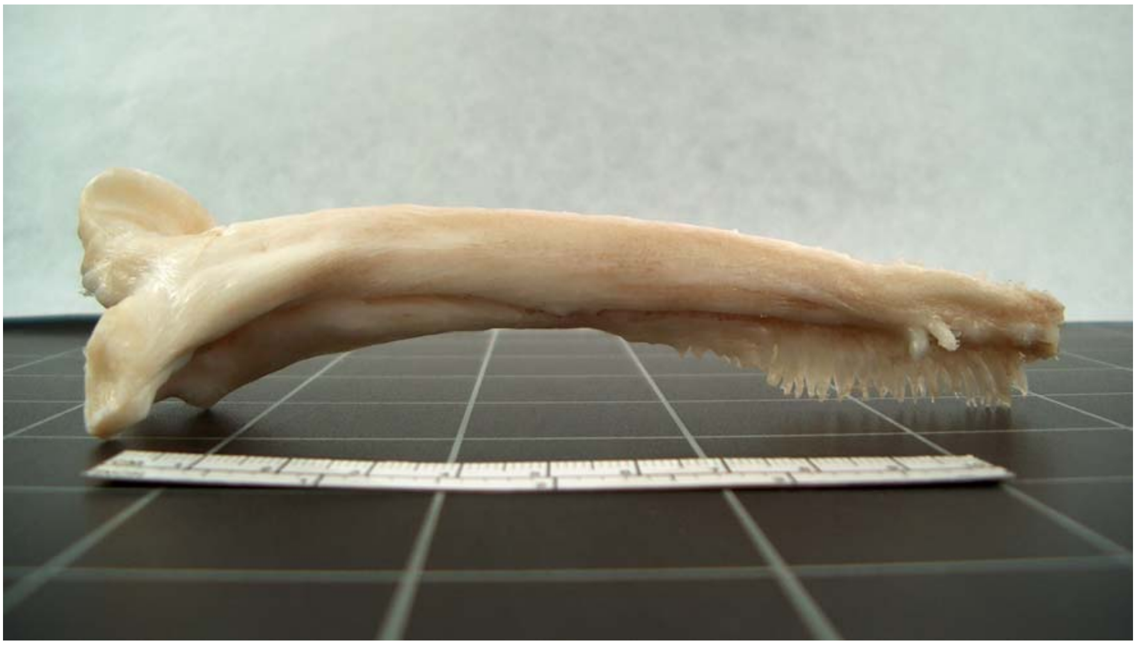

Figure 12. First pectoral fin ray of European catfish.

Article 1

The effects of limnological features on fish assemblages of 14 Spanish resrevoirs

Ecology of Freshwater Fish (2006), 15: 66-77

J. Carol, L. Benejam, C. Alcaraz, A. Vila-Gispert, L. Zamora, E. Navarro, J. Armengol, E. García-Berthou. “The effects of limnological features on fish assemblages of 14 Spanish reservoirs”. *Ecology of Freshwater Fish*. Vol. 15, issue 1 (March 2006) : p. 66–77.

http://doi:10.1111/j.1600-0633.2005.00123.x

Abstract

The relationship of water quality and fish assemblages has been poorly documented in European reservoirs, despite being important for water management and ecological monitoring. We sampled the fish assemblages of 14 Spanish reservoirs by boat electrofishing in the littoral and multi-mesh gillnets in the limnetic zone. Simultaneously, we assembled eight physical descriptors and we measured 20 water quality features of the reservoirs. Multivariate analysis (ordination methods and generalised additive models) showed that altitude and trophic state (indicated by chlorophyll or nutrient concentrations) independently explained most of the variation of fish assemblages in these reservoirs. The most eutrophic reservoirs were dominated by common carp (*Cyprinus carpio*) whereas oligotrophic reservoirs presented other fish species intolerant to pollution rather native (such as brown trout, *Salmo trutta*). The absolute and relative abundance of common carp was strongly related to the trophic state of the reservoir and 40% of its variation was explained by total phosphorous concentration. Despite clear changes in species composition, there was no significant effect of water quality on overall fish richness or Shannon's diversity, suggesting that for such low richness assemblages species composition is a better indicator of cultural eutrophication of reservoirs than fish diversity.

Article 2

Gillnet selectivity and its relationship with body shape for eight freshwater fish species

Journal of Applied Ichthyology (2007), 23: 654-660

J. Carol, E. García-Berthou. “Gillnet selectivity and its relationship with body shape for eight freshwater fish species”. *Journal of Applied Ichthyology*. Vol. 23, issue 6 (December 2007) : p. 654–660.

http://doi:10.1111/j.1439-0426.2007.00871.x

Abstract

Knowledge of the size-selectivity of fishing gear types is crucial to fisheries management and ecology. The gillnet selectivity of most freshwater fish is poorly known. We caught 694 individuals of eight widely-distributed freshwater fish species (seven cyprinids and the pikeperch, *Sander lucioperca*) with multi-mesh gillnets in Spanish reservoirs. The SELECT method was applied to fit four different gillnet selectivity models (normal location, normal scale, lognormal, and gamma). The normal scale model (spread proportional to mesh size) had the best fit in four of the eight fish species. Predicted modal lengths for the best fit models are given to describe gillnet selectivity for the eight fish species. Significant variation in the selectivity parameters was explained by simple shape descriptors such as percent girth or percent depth, suggesting that these shape descriptors might be used as a preliminary tool to describe gillnet selectivity for other fish species.

Article 3

On the spread of the European catfish (*Silurus glanis*) in the Iberian Peninsula: first record in the Llobregat river basin

Limnetica (2007), 26 (1): 169-172

Limnetica, 26 (1): 169-171 (2007)

On the spread of the European catfish (*Silurus glanis*) in the Iberian Peninsula: first record in the Llobregat river basin

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ABSTRACT

On the spread of the European catfish (*Silurus glanis*) in the Iberian Peninsula: first record in the Llobregat river basin

The first record of the European catfish (*Silurus glanis* L. 1758) introduced to the Llobregat river basin (NE Spain) is reported. We captured one individual of this silurid fish species (of a total of 541 fish) in La Baells reservoir on 30 August 2006. Given the low catchability of this fish species, the popularity among some anglers, and old rumours on this introduction, we hypothesize that this species has been present in the reservoir since a few years ago, despite we did not capture it in two previous surveys. The illegal introduction of this and other exotic species to other Iberian river basins should be prevented by the Spanish administration.

Key words: Wels catfish, Siluridae, La Baells reservoir, Spain, invasive fish.

RESUMEN

Sobre la dispersión del siluro (**Silurus glanis*****) en la Península ibérica: primera cita en la cuenca del río Llobregat***

*Se da la primera cita de siluro (*Silurus glanis *L. 1758) introducido en la cuenca del río Llobregat (Cataluña). Se capturó un individuo de esta especie de silúrido (de un total de 534 peces) en el embalse de La Baells el 30 de agosto de 2006. Dada la baja capturabilidad de este pez, su popularidad entre algunos pescadores deportivos, y viejos rumores de esta introducción, sugerimos que esta especie está presente desde hace algunos años, a pesar que no la detectamos en dos muestreos previos. La introducción ilegal de ésta y otras especies exóticas en otras cuencas ibéricas debería ser evitada por la administración española.*

Palabras clave: *Siluridae, embalse de La Baells, España, peces invasores.*

Article 4

Preliminary telemetry data on the movement patterns and habitat use of European catfish (*Silurus glanis*) in a reservoir of the River Ebro, Spain

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Abstract

Knowledge of the movements and diel behaviour of the European catfish (*Silurus glanis*), the largest European freshwater fish, is limited to anecdotal information. In a preliminary telemetry study of European catfish, the spring diel movement patterns of five adult catfish were examined. After intraperitoneal insertion of the acoustic tags, the positions of the fish were recorded automatically in the Flix Reservoir (River Ebro, NE Spain). A marked nocturnal mobility pattern was observed throughout the study. During daytime, the catfish were consistently located in the littoral zone and spent extended periods of the day hidden in concealed habitats. Catfish movements were in a radial pattern, with upstream and downstream excursions followed by returns to a previously occupied location. Significant individual variations in movement pattern were observed among the tagged fish and within the 24 h cycle for each fish. Mean instantaneous swimming speed was 0.17 body lengths per second ($BL \cdot s^{-1}$) at night but 0.09 $BL \cdot s^{-1}$ during the daytime.

Article 5

Growth and diet of European catfish (*Silurus glanis*) in early and late invasion stages

Growth and diet of European catfish (*Silurus glanis*) in early and late invasion stages

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Key words: Silurus glanis*, Iberian Peninsula, ecological impact, introduced fish, invasive species*

ABSTRACT

The ecological impact of many invasive species is usually unknown because of the absence of data before the introduction. We demonstrate the utility of comparing early and late invasion stages to understand the ecological changes caused by invasive species, particularly in large species and ecosystems (such as reservoirs) that are not easily amenable to experimental work. We report the first growth and diet data for European catfish (*Silurus glanis*) in the Iberian Peninsula and compare three populations in the river Ebro corresponding to the oldest introduction (ca. 30 years) in the Iberian Peninsula with two recent introductions (reservoirs in the Ter river). Total length and age of catfish varied significantly among populations and recent introductions had smaller and younger catfish with growth rates higher than old and native populations; a 7+ old catfish was ca. 100 cm in old populations and 150 cm in recent introductions. Diet also depended on site and catfish size. Catfish measuring less than 30 cm consumed mostly invertebrates and plant material, shifting thereafter to prey on crayfish (old introductions) or fish (recent introductions). A number of fish species were present in stomachs but common carp and birds were only present in very large fish (> 120 cm). The abundance of waterbirds, particularly anatids, was significantly lower in reservoirs with catfish, suggesting direct ecological impact on or learning avoidance by waterbirds. Our results suggest that in early stages of invasion, catfish displays higher growth rates by profiting from unexploited resources (large fish and secondarily waterbirds), shifting to other prey (and reducing growth) in late invasion stages.

Synopsis and general discussion

Fish assemblages of Catalan reservoirs

Nineteen fish species were captured in Catalan reservoirs and eleven of them were introduced. Fish richness was low in Catalan reservoirs (maximum of eight species detected per reservoir) as in the rest of Iberian Peninsula (Doadrio *et al.* 1991), Mediterranean (Moyle & Marchetti 1999) and European freshwater ecosystems in general (Gassner *et al.* 2003). The biotic homogenisation characteristic of reservoirs (Rahel 2002) was also observed since the most abundant species (bleak *Alburnus alburnus*, common carp *Cyprinus carpio*, largemouth bass *Micropterus salmoides*, roach *Rutilus rutilus*, pikeperch *Sander lucioperca* and rudd *Scardinius erythrophthalmus*) were all native to many parts of Europe and introduced elsewhere.as game fishes (big predators) or bait and forage fish (medium-size cyprinids) (Clavero & García-Berthou, 2006) The European catfish (*Silurus glanis*) was also captured in this study in few reservoirs with low numbers.

Fish were sampled by boat electrofishing (active gear) and multi-mesh gillnets (passive gear) in the limnetic zone. The use of multiple sampling gears is needed to ensure that most species and size classes are sampled and to assess the fish assemblage as completely as possible (Goffaux *et al.* 2005). Electrofishing is the most adequate method for describing assemblage structure in most shallow freshwater ecosystems (Zalewski & Cowx 1989). Gillnets are widely used as a research tool to sample fish populations and multi-mesh size reduces the effect of size selectivity. In Catalan reservoirs boat electrofishing was only used in the littoral zone and gillnets was used in the limnetic zone, where electrofishing is ineffective due to higher depth.

We modelled gillnet selectivity using the SELECT method for eight freshwater fish species and observed that the SELECT method is a powerful framework to develop different models. Shape descriptors such as % girth and % depth might be used as a preliminary tool to understand gillnet selectivity for fish species for which selectivity has never been studied.

Limnology and fish assemblages

Evaluating the effects of limnological features on fish assemblages we observed that altitude and trophic state were the most important descriptors of variation of fish assemblages in Catalan Reservoirs. Most eutrophic reservoirs (that were of low altitude) were dominated by common carp (*C. carpio*) and secondarily other species such as goldfish (*C. auratus*) and, if passage is possible, eel (*A. anguilla*). In artificial and stressed ecosystems such as reservoirs the role of altitude probably mediates less the trophic level than in natural lakes or other aquatic ecosystems.

We found a strong significant relationship of the absolute and relative abundances of common carp with trophic state both in the littoral and limnetic zone (independently with electrofishing and gillnet data). Lee & Jones (1991) also suggested that in most eutrophic U.S. reservoirs common carp dominated and this condition was difficult to reverse because of the well-known effects of carp of increased turbidity and decline of macrophytes (Crivelli 1983; Lougheed *et al.* 1998).

Despite the clear effects of trophic state on the fish assemblages, total fish species richness was not significantly related to the annual mean of total phosphorus. Similarly, the negative correlation of Shannon's diversity index with the total phosphorous was very low and not significant for the littoral and the limnetic zone.

Introduction and ecology of European catfish

The European catfish is nowadays illegally introduced in three Catalan river basins. It has been introduced to the Ebro river basin for 30 years (Elvira & Almodóvar 2001; Doadrio 2002), to the Ter river basin for a few years (Carol *et al.* 2003) and was first captured in Llobregat river basin during a fish survey in 2006 (see Article III).

Our data confirmed that catfish grows quickly and can reach between 300 and 500 mm in the first year and can reach more than 2.5 m. It also may live up to 20 years. Males of catfish were significantly larger than females, like in Haffray *et al.* (1998) where males grew form 2 to 15% faster than males. Estimated total lengths and age determination data confirmed that recent introductions (Sau and Susqueda reservoir in Ter river basin) were growing faster than Ebro ones (Riba-roja and Flix) and other populations in native areas. We also observed a diverse diet in catfish, including invertebrates, many fishes and even birds. Catfish modified its diet during ontogeny, consuming mainly invertebrates and plant material when young and crayfish and cyprinid fishes when older (Maitland 2000; Wysujack 2005). The movement patterns of catfish confirmed that it was distinctly nocturnal, like in Boujard (1995) under laboratory conditions, but in contrast of Slavík (2007) data in Berounka river (Czech Republic), where strictly nocturnal activity occurred only for adults in autum. During daytime, the fish remained in the littoral zone and at night large displacements were undertaken to explore a small area and return to a previously occupied location (resting place) like in Lake Biwa where native catfish (*Silurus biwaensis*) did not change its resting places throughout the year (Takai *et al.* 1997). The resting places were within dense vegetation near tree trunks or large stones like in Abdullayev *et al.* (1978) and Bruton (1996). The nocturnal peak in mobility appears to be motivated by hunger stimuli. Movements should be related to external factors represented by temperature, flow, light intervals... (Slavík *et al.* 2007).

Further telemetry data in the Ebro reservoirs not included in this thesis (Carol et al., unpublished data) show that although the activity of catfish varies seasonnaly, there is site fidelity throughout the year to the same resting place like Biwa catfish (Takai *et al.* 1997). In summer, movements are more frequent in dusk and night but disappear during daytime, probably because of the high water temperatures and low oxygen concentration. In autumn, daytime movements increase and in winter catfish seems more active during daytime than at night.

The diet of European catfish also depended on sites, since catfish mainly consumed crayfish in Ebro's reservoirs but cyprinids in Ter's reservoirs. We observed that small fish species are less abundant in Ebro's reservoirs than in the rest of Catalan reservoirs. In contrast, large individuals of carp and other cyprinid species dominated in Flix and Riba-roja. On the contrary, the diet in recent catfish introductions (Ter reservoirs) was dominated by cyprinids mainly because the higher abundance of cyprinid fish prey such as roach and bleak.

In the Iberian Peninsula, some studies have already shown that invasive fishes have a negative impact on the native fish fauna. In Elvira & Barrachina (1996), 11 fish species native in the National Park of Daimiel (Guadiana River Basin) were found to have become extinct during the twentieth century. Pike (*Esox lucius*) was the principal cause of these extinctions through predation. In the absence of suitable prey items, the pike itself disappeared. A similar situation was found in 14 lakes joined by short streams in the Natural Park of the Ruidera Lakes (also in the Guadiana River basin) (Elvira & García-Utrilla 1991; Almodóvar & Elvira 1994). A study of diet suggested that the native fish species were already on the limit of extinction and another exotic species, the red swamp crayfish (*Procambarus clarkii*), was the most common prey item for pike (Elvira *et al.* 1996). It was inferred that pike initially fed on native fish, but when these stocks disappeared they switched their diet to crayfish (Elvira *et al.* 1996). The diet of largemouth bass (*Micropterus salmoides*) from the same area (Nicola *et al.* 1996) and in Banyoles Lake (García-Berthou 2002), one of the Iberian freshwater ecosystems with oldest introductions, was similar.

We hypothesize that in early stages of invasion cyprinid fish dominate in the diet and that when fish population is depleted, the catfish starts to consume other less profitable taxa such as crayfish. This pattern might be general in introductions of large piscivorous. Although the native fish species probably were already not abundant in reservoirs, where fish assemblages are often dominated by exotic fish species, in the river ecosystems, where catfish is also abundant, some native and endemic species such as Iberian barbel (*Barbus graellsii*), small Mediterranean barbels (*Barbus meridionalis* and *Barbus haasi*), chub (*Squalius cephalus*), Iberian nase (*Chondrostoma miegii*), eel (*Anguilla* anguilla), freshwater blenny (*Salaria fluviatilis*) are still present and will probably be severely impacted by the catfish. So illegal fish introductions like European catfish should receive more attention from academic research and from public administration (García-Berthou in press)

Management implications

Although introductions of exotic species are theoretically regulated by legislation in most European countries it is observed a proliferation in the number of still waters containing *S. glanis* in the last 20-30 years (Copp *et al.* 2005). Spanish policy has recently become more environmentally conscious but fish introduction and translocation continues to be largely uncontrolled by fish management authorities and little is done to improve education, management practices and prevention. Furthermore, private interests (anglers, fish farmers and owners, aquaculture…) are frequently in favour of introductions because of potential economic benefits (Hickley and Chare, 2004). To reduce problems from species introductions and to develop a protocol for controlling invasive species, information on the potential impacts is urgently needed. Unless profound changes in current Spanish fisheries management and policy are undertaken, we predict the introduction of more exotic fish species to the rest of Iberian river basins in the near future, where many fish species endemic are already endangered, whilst those already established species such as catfish will probably become more widespread.

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Conclusions

CONCLUSIONS

1. Altitude and trophic state (indicated by chlorophyll or nutrient concentrations) independently explained most of the variation of fish assemblages in Catalan (NE Spain) reservoirs.

2. The absolute and relative abundance of common carp (*Cyprinus carpio*) was strongly related to the trophic state of the reservoir (explaining ca. 40% of phosphorous concentration variation), the most eutrophic Catalan reservoirs being dominated by common carp.

3. Despite clear changes in species composition, there was no significant effect of water quality on overall fish richness or Shannon's diversity, suggesting that for such low richness assemblages species composition is a better indicator of cultural eutrophication of reservoirs than fish diversity.

4. We developed gillnet selectivity models for eight fish species (such as bleak *Alburnus alburuns*, common carp *Cyprinus carpio*, roach *Rutilus rutilus*, or rudd *Scardinius erythrophthalmus*), many of which are invasive species, widely distributed and with no published selectivity models. Significant variation in the selectivity parameters was explained by simple shape descriptors such as percent girth or percent depth, suggesting that these shape descriptors might be used as a preliminary tool to describe gillnet selectivity for other fish species.

5. The European catfish nowadays inhabit in four Iberian river basins. It has been introduced in the Ebro river basin for 30 years, in the Ter and Tajo river basin for a few years and in 2006 was first captured in Llobregat river basin.

6. A marked nocturnal mobility pattern was observed in a preliminary telemetry spring study of European catfish. During daytime, the catfish were consistently located in the littoral zone and spent extended periods of the day hidden in concealed habitats. Catfish movements were in a radial pattern, with upstream and downstream excursions followed by returns to a previously occupied location. Significant individual variations in movement pattern were observed among the tagged fish and within the 24 h cycle for each fish.

7. Total length and age of catfish varied significantly among populations and recent introductions had smaller and younger catfish with growth rates higher than old and native populations. Diet also depended on site and catfish size. Catfish measuring less than 30 cm consumed mostly invertebrates and plant material, shifting thereafter to prey on crayfish (old introductions) or fish (recent introductions). We demonstrate the utility of comparing early and late invasion stages to understand the ecological changes caused by invasive species, particularly in large species and ecosystems (such as reservoirs) that are not easily amenable to experimental work.

Conclusions

(en català)

CONCLUSIONS

1. L'altitud i l'estat tròfic (indicat per la clorofil·la o les concentracions de nutrients) expliquen, de forma independent, la major part de variació de les comunitats de peixos dels embassaments catalans (NE Espanya).

2. Les abundàncies absolutes i relatives de la carpa (*Cyprinus carpio*) estan fortament relacionades amb l'estat tròfic dels embassaments (explicant un 40% per la variació de la concentració de fósfor total); els embassaments catalans més eutròfics estan dominats per carpa.

3. Tot i els canvis en la composició d'espècies, no es va trobar efecte significatiu de la qualitat de l'aigua sobre la riquesa o diversitat de peixos, suggerint que en aquestes comunitat de baixa riquesa, la composició d'espècies és millor indicador de l'eutrofització antròpica que la diversitat de peixos.

4. Hem desenvolupat els models de selectivitat de xarxes de llum variable per vuit espècies de peixos (com l'alburn *Alburnus alburuns*, carpa *Cyprinus carpio*, madrilleta vera *Rutilus rutilus*, o el gardí *Scardinius erythrophthalmus*), la majoria d'elles espècies invasores àmpliament distribuïdes i sense models de selectivitat publicats. Simples descriptors de forma com el % de perímetre màxim o el % d'alçada màxima del cos expliquen variacions significatives en els paràmetres de selectivitat. Això, suggereix la utilització d'aquests descriptors com eines preliminars per tal de descriure la selectivitat de les xarxes de llum variable d'altres espècies de peixos.

5. El silur es troba actualment introduït a quatre conques ibèriques. Fou introduït a la conca de l'Ebre fa uns 30 anys, a les conques del Ter i el Tajo fa uns pocs anys i el 2006 el vam capturar a la conca del Llobregat.

6. Observem un marcat patró de mobilitat nocturna en l'estudi preliminar de telemetria del silur. Durant la major part del dia el silur es troba en la zona litoral i passa llargs períodes de temps refugiat en amagatalls. Els moviments del silur presenten un patró radial, amb excursions amunt i a avall al llarg de l'eix principal de l'embassament seguides de retorns al lloc d'origen. S'han observat variacions individuals significatives en el patró de moviments dels silurs marcats i també variacions significatives en els cicles diaris de cada individu.

7. La longitud total i l'edat varien significativament entre les poblacions de silur estudiades. Les introduccions recents presenten silurs més joves, de menor mida i amb taxes de creixement superiors a les de les poblacions introduïdes anteriorment i també respecte les poblacions natives. La dieta del silur depèn també del lloc i la seva mida. Silurs menors de 30 cm s'alimenten majoritàriament de invertebrats i matèria vegetal, i a mesura que creiexen depreden sobre crancs de riu (les introduccions antigues) o peixos (les introduccions recents). Hem demostrat la utilitat de comparar estadis de invasió recents i avançats per al de mirar d'entendre els canvis ecològics causats per espècies invasores, particularment en grans espècies com el silur i en grans ecosistemes com els embassaments, on el treball experimental no resulta fàcil.

Conclusiones

CONCLUSIONES

1. La altitud y el estado trófico (indicado por la clorofila o concentraciones de nutrientes) explican, de forma independiente, la mayor parte de variación de las comunidades de peces de los embalses catalanes (NE España).

2. Las abundancias absolutas y relativas de la carpa (*Cyprinus carpio*) están fuertemente relacionadas con el estado trófico de los embalses (explicándose un 40 % por la variación de la concentración de fósforo total), estando los embalses más eutróficos dominados por carpa.

3. A pesar de los claros cambios en la composición de especies, no se halló efecto significativo de la calidad del agua en la riqueza o diversidad de peces, lo que sugiere que en estas comunidades con baja riqueza, la composición de especies es mejor indicador de la eutrofización antrópica que la diversidad de peces.

4. Hemos desarrollado los modelos de selectividad de ocho especies de peces de agua dulce (alburno *Alburnus alburuns,* carpa *Cyprinus carpio,* rutilo *Rutilus rutilus,* escardinio *Scardinius erythrophthalmus,…*), la mayoría de ellas especies invasoras ampliamente distribuidas y sin modelos de selectividad publicados. Simples descriptores de forma como el % de perímetro máximo o el % de altura máxima del cuerpo explican variaciones significativas en los parámetros de selectividad. Esto sugiere la utilización de

estos descriptores como herramientas preliminares para describir la selectividad de las redes de luz variable de otras especies de peces.

5. Actualmente, el siluro se encuentra introducido en 4 cuencas Ibéricas. Fue introducido en la cuenca del río Ebro hará unos 30 años, en las cuencas del Ter y del Tajo hace unos pocos años y en el 2006 se capturó por primera vez en la cuenca del Lllobregat.

6. Observamos un marcado patrón de movilidad nocturna en el estudio preliminar de telemetría del siluro. Durante el día, el siluro se encuentra persistentemente en la zona litoral y pasa largos períodos del día refugiado en escondrijos. Los movimientos del siluro presentan un patrón radial, con excursiones arriba y abajo del eje principal del embalse seguidas de retornos al sitio de origen. Se han observado variaciones individuales significativas en el patrón de movimientos de los siluros marcados y también variaciones significativas en los ciclos diarios de cada individuo.

7. La longitud total y la edad varían significativamente entre las poblaciones de siluro estudiadas. Las introducciones recientes presentan siluros más jóvenes, de menor tamaño y con taxas de crecimiento mayores a las de las poblaciones introducidas anteriormente y también en relación a las poblaciones nativas. La dieta del siluro depende también del lugar y de su tamaño. Siluros menores de 30 cm consumen mayoritariamente invertebrados y materia vegetal, a mayores tamaños predan sobre cangrejos de río (las introduccions antiguas) o peces (las introducciones recientes).

Hemos demostrado la utilidad de comparar estadios de invasión recientes y avanzados para entender los cambios ecológicos causados por especies invasoras, particularmente en grandes especies como el siluro y grandes ecosistemas como los embalses, dónde el trabajo experimental no es fácil.