Socio-economics of aquatic bioinvasions in Catalonia
Reflexive science for management support

Beatriz Rodríguez Labajos

October 2014

PhD Programme in Environmental Sciences

at the

Autonomous University of Barcelona (UAB)

Institut de Ciència i Tecnologia Ambientals (ICTA)

Supervisors

Dr. Joan Martínez Alier

Autonomous University of Barcelona

Dr. Sigrid Stagl

Vienna University of Economics and Business

Abstract

Aquatic bioinvasions are a major pressure to global freshwater biodiversity, a priority of environmental and water management and also a rising social concern due to perceive socioeconomic impacts. The purpose of this dissertation is to document and explain the socioeconomic elements of bioinvasions in aquatic ecosystems in Catalonia and how, in this context, scientific work is used to shed light into knowledge gaps for management. Specifically, the objectives of the thesis are:

i. To explore and assess approaches for addressing the knowledge gaps regarding driving forces, impacts and the preparation of responses to aquatic bioinvasions.

ii. To reveal how management, the scientific activities supporting management, and the different agencies involved interact regarding the socioeconomic elements of aquatic bioinvasions.

iii. To propose guidelines for management of alien species in aquatic ecosystems in Catalonia that take into account the knowledge gaps along the invasion process.

From the theoretical point of view, the dissertation brings together the literatures of ecological economics, conservation and invasion biology, water management and uncertainty studies. The research responds to a reflexive model of science, which entails engagement with the observed processes. The use of the DPSIR framework has been useful to organize the information available from direct and long-lasting contact with the research topic.

Chapter 1 describes the problématique of alien invasive species (AIS) management in aquatic ecosystems, using the case of Catalonia at two scales, the regional level and the local level in two study areas. There, two species, *Dreissena polymorpha* and *Silurus glanis* help to focus the analysis.

In **Chapter 2**, driving forces of biological invasions have been examined under two different approaches. First, generic driving forces of biological invasions have been examined through literature review. Second, the driving forces of *the D. polymporpha* and the *S. glanis* invasions have been analysed using participatory methods in a post-invasion context.

Chapter 3 offers insights on the consideration of impacts of aquatic AIS. A framework for the identification of impacts, relying on the ecosystem service approach, is used to understand direct impacts from different taxa present in aquatic ecosystems in Catalonia. Based on quantitative information about costs from the an invaded context (the Ebro), estimates of the potential monetary impacts of the zebra mussel in a non-affected area (the Ter), have been generated for three possible scenarios('No action', 'Mitigation', 'Adaptation') along four stages of the invasion process that are relevant for management.

Chapter 4 brings together three different approaches to address uncertainties that emerge while preparing responses to invasion processes. First, the existing experiences about risk assessment of aquatic bioinvasions are reviewed, describing the state-of-the-art situation in Catalonia. Second, Biocontamination and Biopollution (BC&BP) indices are assessed as an option to integrate AIS and their impacts in the ecological status classification of water bodies. Third, the advantages and disadvantages of participatory and analytic approaches to scenario development are studied. Qualitative scenarios are developed for the post-invasion context and analytic scenarios are designed for the pre-invasion context. The issue of inter-scale interaction in scenario development is also addressed.

Based on the findings from previous chapters, **chapter 5** introduces a set of general rules to increase the effectiveness of AIS management. They are related with the setting of management objectives, the

improvement of coordination, the creation of information hubs, the tackling of bioinvasional meltdowns and common enemies, the focus of public awareness towards integrated debates about water quality, the appropriateness of working scales and encouragement of local agency, networking, the use of suitable methods to tackle uncertainty and the agenda for management-focused research. Final considerations are offered on the challenges and benefits of a reflexive model of science for AIS management.

Keywords:

invasive species
aquatic ecosystems
management
water quality
local agency
risk assessment
scenarios
DPSIR framework
multi-level governance
reflexivity
science in society

Resumen

Las bioinvasiones acuáticas suponen una presión para la biodiversidad de los ecosistemas acuáticos continentales, son una prioridad para la gestión ambiental y del agua, y también una preocupación social creciente, debido a la percepción de impactos socioeconómicos. El propósito de esta tesis doctoral es documentar y explicar los aspectos socioeconómicos de las bioinvasiones en los ecosistemas acuáticos en Cataluña y, dentro de este ámbito, cómo se ha utilizado el trabajo científico en situaciones de falta información necesaria para la gestión.

Concretamente, los objetivos de la tesis son:

i) Explorar y evaluar enfoques para abordar el conocimiento sobre fuerzas motrices, los impactos y las respuestas a las bioinvasiones.

ii) Revelar las interacciones entre la gestión y la investigación respecto a los aspectos socioeconómicos de las bioinvasiones acuáticas.

iii) Proponer directrices para la gestión de especies exóticas en ecosistemas acuáticos en Cataluña que tengan en consideración los vacíos de información sobre los proceso de invasión.

Desde el punto de vista teórico, la tesis reúne las literaturas de la economía ecológica, la biología de la conservación y de las invasiones biológicas, la gestión del agua y los estudios sobre incertidumbre. La investigación responde a un modelo reflexivo de la ciencia, que implica una vinculación comprometida con los procesos observados. La utilización de la marco DPSIR ha sido útil para organizar la información disponible, tras un contacto directo y duradero con el tema de investigación.

El **capítulo 1** describe la problemática de la gestión de las especies exóticas invasoras (EEI) en ecosistemas acuáticos en el caso de Cataluña, a dos escalas, regional y local, en dos áreas de estudio. Allí, dos especies, *Dreissena polymorpha* y *Silurus glanis* ayudan a enfocar el análisis.

En el **capítulo 2**, se examinan las fuerzas motrices de las invasiones biológicas bajo dos enfoques. En primer lugar, los factores que impulsan las invasiones biológicas, de manera genérica, se han revisado a diferentes niveles a través de una revisión de literatura. En segundo lugar, las los factores determinantes en las invasiones de *D. polymporpha* y *S.glanis se* analizan utilizando métodos participativos.

El **capítulo 3** ofrece diversas perspectivas para la consideración de los impactos de las EEI acuáticas. Un marco para la identificación de los impactos, basado en el enfoque de los servicios ambientales, sirve para entender los impactos directos de diferentes grupos taxonómicos presentes en los ecosistemas acuáticos en Cataluña. A partir de información cuantitativa sobre los costes de la invasión compilados en un contexto post-invasión (el Ebro), se han estimado los impactos monetarios del mejillón cebra en una zona no afectada (el Ter), en torno a tres posibles escenarios ("No acción", 'Mitigación', 'Adaptación'), a lo largo de cuatro etapas del proceso de invasión que son relevantes para la gestión.

El **capítulo 4** reúne tres enfoques diferentes para abordar las incertidumbres que surgen a la hora de preparar respuestas a los procesos de invasión. En primer lugar, se revisan las experiencias existentes sobre evaluación de riesgo de bioinvasiones acuáticas, describiendo el estado de la cuestión en Cataluña. En segundo lugar, se evalúan los índices de biocontaminación y biopolución (BC&BP) como opción para integrar las EEI y sus impactos en la clasificación del estado ecológico de los cuerpos de agua. En tercer lugar, se estudian las ventajas y desventajas de los enfoques participativos y analíticos para el desarrollo de escenarios. Para ello, se desarrollan escenarios participativos para el contexto post-invasión y

escenarios analíticos para el contexto pre-invasión. También se aborda la cuestión de la interacción entre escalas en el desarrollo de escenarios.

A partir de las conclusiones de los capítulos anteriores, el **capítulo 5** presenta un conjunto de reglas generales para aumentar la eficacia de la gestión de EEI. Están relacionadas con el establecimiento de objetivos de gestión, la mejora de la coordinación, la creación de centros de información, la lucha contra los 'colapsos bioinvasionales' y los enemigos comunes, el enfoque de la atención pública en debates sobre calidad del agua, la adecuación de las escalas de trabajo y fomento de la agencia local, las redes, el uso de métodos adecuados para enfrentar la incertidumbre y la búsqueda de agenda de investigación orientada a la gestión. Se ofrecen, finalmente, algunas consideraciones sobre los desafíos y beneficios de un modelo reflexivo de la ciencia para la gestión de EEI.

Palabras clave:

especies invasoras	agencia	governanza multi escalar
ecosistemas acuáticos	evaluación de riesgos	reflexividad
gestión	escenarios	ciencia y sociedad
calidad del agua	DPSIR	

Resum

Les bioinvasions aquàtiques suposen una pressió per a la biodiversitat dels ecosistemes d'aigües continentals, són una prioritat per a la gestió ambiental i de l'aigua i també una preocupació social creixent, a causa de la percepció dels seus impactes sòcio-econòmics. El propòsit d'aquesta tesi és documentar i explicar els aspectes socioeconòmics de les bioinvasions en ecosistemes aquàtics a Catalunya i, dins d'aquest àmbit, com s'ha utilitzat el treball científic en situacions de falta informació necessària per a la gestió. En concret, els objectius de la tesi són:

i) Explorar i avaluar enfocaments per comprendre les forces motrius, els impactes i les respostes a la bioinvasions.

ii) Revelar les interaccions entre gestió i recerca sobre aspectes socioeconòmics de les bioinvasions aquàtiques.

iii) Proposar directrius per a la gestió d'espècies exòtiques en ecosistemes aquàtics a Catalunya que tinguin en consideració llacunes informació sobre els processos d'invasió.

Des del punt de vista teòric, la tesi reuneix les literatures de l'economia ecològica, la biologia de la conservació i de les invasions biològiques, sobre gestió d'aigües i del estudis sobre la incertesa. La recerca respon a un model reflexiu de la ciència, que implica una vinculació compromesa amb els processos observats. L'ús del marc DPSIR ha estat útil per organitzar la informació disponible, després d'un contacte directe i durador amb el tema de recerca.

El **capítol 1** descriu la problemàtica de la gestió d'espècies exòtiques invasores (EEI) en ecosistemes aquàtics en el cas de Catalunya, a les dues escales, regional i local, en dues àrees d'estudi. Allà, dues espècies *Dreissena polymorpha* i *Silurus glanis* ajuden a enfocar l'anàlisi.

El **capítol 2** examina les forces impulsores de les invasions biològiques sota dos enfocaments diferents. En primer lloc, els factors que impulsen les invasions biològiques, genèricament, s'han revisat a diferents nivells, a través d'una revisió bibliogràfica. En segon lloc, els determinants en les invasions *de D. polymporpha* i *S.glanis* han estat analitzats utilitzant mètodes participatius.

El **capítol 3** ofereix diverses perspectives per a la consideració dels impactes de les EEI aquàtiques. Un marc per a la identificació d'impactes, basat en l'enfocament dels serveis ambientals, ha servit per entendre l'impacte directe de diferents grups taxonòmics presents en els ecosistemes aquàtics a Catalunya. Informació quantitativa de les despeses de la invasió compilada en un context post-invasió (a l'Ebre), ha permès estimat els impactes monetàries del musclo zebrat a una zona no afectada (al Ter), sota tres escenaris possibles ("Sense acció", "Mitigació", "Adaptació"), al llarg de quatre etapes del procés invasió que són rellevants per a la gestió.

El **capítol 4** reuneix tres enfocaments diferents per encarar les incerteses que es plantegen en la preparació de respostes als processos d'invasió. En primer lloc, es revisen les experiències existents en l'avaluació del risc de les bioinvasions aquàtiques, descrivint l'estat de la qüestió a Catalunya. En segon lloc, índexs de biocontaminació i biopol·lució (BC&BP) s'avaluen com a opció per integrar les EEI i els seus impactes en la classificació de l'estat ecològic de les masses d'aigua. En tercer lloc, s'observen els avantatges i desavantatges d'aproximacions analítiques i participatives al desenvolupament d'escenaris. Per això, s'han desenvolupat escenaris qualitatives en un context de post-invasió i escenaris analítics en un context pre-invasió. També s'aborda la qüestió de la interacció entre les escales en escenaris de desenvolupament.

Basat en les conclusions dels capítols anteriors, el **capítol 5** presenta presenta un conjunt de directrius per augmentar l'eficàcia de la gestió de les EEI. Estan relacionades amb l'establiment d'objectius de gestió, la millora de la coordinació, la creació de centres d'informació, la lluita contra els 'col·lapses bioinvasionals' i els enemics comuns, l'enfocament de l'atenció pública en els debats sobre la qualitat de les aigües, l'adequació de les escales de treball i la promoció de l'agència local, el desenvolupament de xarxes, l'ús de mètodes adequats per afrontar la incertesa i el desenvolupament de l'agenda de recerca orientada a la gestió. Finalment, s'ofereixen algunes consideracions sobre els reptes i els beneficis d'un model reflexiu de la ciència en la gestió de les EEI.

Paraules clau:

espècies invasoras
ecosistemes aquàtics
gestió
qualitat del agua
agència
avaluació de riscs
escenaris
DPSIR
governança multi-escalar
reflexividad
ciència i societat

Contents

Acronyms and abbreviations

AEMS -	Asociación para el Estudio y Mejora de los Salmónidos - Ríos con Vida
ALARM	Assessing LArge scale Risks for biodiversity with tested Methods
AS	alien species
BC&BP	biocontamination and biopollution
BQE	biological quality elements
BQI	biological quality indicators
CBD	Convention on Biological Diversity
DGMNB	General Directorate of Natural Environment and Biodiversity
EFSA	European Food Safety Authority
ES	ecosystem services
ETAP	*estación de tratamiento de agua potable* [drinking water treatment plant]
FISK	Freshwater Fish Invasiveness Scoring Kit
FWE	freshwater ecosystems
GloBallast	Global Ballast Water Management Programme
IAS	invasive alien species
IB	Interregional Basins
IBC	Internal Basins of Catalonia
IPCC	International Panel on Climate Change
IS	invasive species
JARC	Joves Agricultors i Ramaders de Catalunya
LPI	Living Planet Index
m	metre (associated with distances)
m	million (associated with currencies)
MSFD	Marine Strategy Framework Directive
NPP	nuclear power plant
RAIS	risks assessments of invasive species
ROR	run-of-the-river (type of hydroelectric plant)
SPS	Sanitary and Phytosanitary Measures (SPS Agreement)
WB	water body
WFD	Water Framework Directive
WRA	Weed Risk Assessment

The ISO 4217 standard is used for the currency codes (e.g., USD for US dollar).

Preface

For six years I had daily contact with the management of zebra mussel and other aquatic invaders. This was not due to purely scientific reasons but because it was my job as a collaborator of the Catalan regional administration. That allowed me to get actively involved with what it had been my object of study during the previous two years. In 2006 I took the decision of accepting that job thinking that that would give me easier access to information of interest for my thesis, which was pretty advanced at that stage. Indeed, access to information increased much beyond my expectations. At the same time my research interests changed, adjusting themselves to the new conditions: better data accessibility, shifting reference frameworks, more chances for interdisciplinary dialogues and also, I admit it, acceptance of the irrelevance of some of my previous research questions.

The present dissertation is an attempt to synthesise the outcome of such process, which included scientific and practical dialogues with different communities, within and outside the academic arena. Besides the specific analyses contained, the dissertation makes a point about the challenges and benefits of a reflexive model of science, based on the experience of engaged scientific practice. At this stage this has become a main motivation for the thesis.

Therefore, this document brings together insights from collaborations with different working groups whose precise participation is acknowledged along the text. These collaborations developed into several publications, listed next, that constitute a vertebral part of several chapters in the thesis.

> Özkaynak, B., Rodríguez-Labajos, B., 2010. Multi-scale interaction in local scenario-building: A methodological framework. Futures 42, 995–1006.
>
> Rodríguez-Labajos, B., Binimelis, R., Monterroso, I., 2009. Multi-level driving forces of biological invasions. Ecol. Econ. 69, 63–75.
>
> Rodriguez-Labajos, B., Binimelis, R., Monterroso, I., Martinez-Alier, J., 2009. The arrival of *Dreissena polymorpha* and *Silurus glanis* in the Ebro River: Socio-economics of interlinked aquatic bioinvasions, in: Rodriguez-Labajos, B. et al. (Ed.), Assessing Biodiversity Risks with Socio-Economic Methods: The ALARM Experience. Pensoft, Sofia, pp. 69–111.
>
> Rodríguez-Labajos, B., Binimelis, R., Cardona, C., Dittmer, K., Martínez-Alier, J., Monterroso, I., Munné, A., 2010. Chronicle of a Bioinvasion Foretold: Distribution and management of the zebra mussel (*Dreissena polymorpha*) invasion in Spain, in: Settele, J. (Ed.), Atlas of Biodiversity Risk. Pensoft, Sofia, pp. 198–201.

The format chosen for presenting the findings from these publications has been to articulate a coherent narrative, instead of presenting them unconnectedly. Besides facilitating the reading across the different contributions mentioned above, previously unpublished information and outcomes from several conference presentations found also their way to pertinent sections of the text. The preparation of a monograph has also helped to pinpoint relevant findings from publications to which the author has contributed and that are not included as chapters or sections but as key references in different parts of the dissertation.

> Andreu, J., Pino, J., Rodríguez-Labajos, B., Munné, A., 2011. Avaluació de l'estat i el risc d'invasió per espècies exòtiques dels ecosistemes aquàtics de Catalunya [*Evaluation of state and risk of alien species invasion in Catalonia's aquatic ecosystems*]. Agència Catalana de l'Aigua, Departament de Medi Ambient i Habitatge, Generalitat de Catalunya.
>
> Binimelis, R., Born, W., Monterroso, I., Rodríguez-Labajos, B., 2007a. Socio-economic impact and assessment of biological invasions. Ecol. Stud. 193 , 331–347.

Binimelis, R., Monterroso, I., Rodriguez-Labajos, B., 2007b. A social analysis of the bioinvasions of *Dreissena polymorpha* in Spain and *Hydrilla verticillata* in Guatemala. Environ. Manage. 40, 555–566.

Ordeix, M; Sostoa, A; Maceda, A; García-Berthou, E; Benejam, L; Casals, F; Caiola, N; Ibàñez, C; Sellarès, N; Pou-Rovira, G; Rodríguez-Labajos, B; Solà, C; Bardina, M; Casamitjana, A i Munné, A. 2014. Els peixos dels rius i les zones humides de Catalunya. Qualitat biològica i connectivitat fluvial. Catalunya [*The fish of Catalonia's rivers and wetlands. Biological quality and river connectivity*]. Agència Catalana de l'Aigua – Museu del Ter – Eumo editorial. Vic. 172 p.

Along the dissertation, the acknowledgements are inclosed in the appropriate sections. This is a deliberate choice, as it makes the information flow transparent and it also serves as an indication of data sources.

Besides the topics directly related with the management of alien species, since I started my PhD studies I have collaborated with other researchers in the preparation of several publications. The experience of conducting participatory workshops for scenario development, with similar methodology of the one presented in this dissertation, was used for the integrated assessment of nutrient flows in a Catalan river catchment (Caille et al., 2007). Evaluation of sustainability at the macro level was undertaken using multi-criteria, based on secondary data (Shmelev and Rodríguez-Labajos, 2009).

Particularly fruitful was the collaboration with the UAB research team in the ALARM project, with an outcome of additional papers besides the ones mentioned above (Binimelis et al., 2009a; Monterroso et al., 2010) and the preparation of six chapters within a collective book on different socio-economic methods for the assessment of risk to biodiversity (B. Rodríguez-Labajos et al., 2009).

In the same vein, a critical review to different approaches to the economics of the ecosystems and biodiversity was recently produced (Rodríguez-Labajos and Martínez-Alier, 2013). This latter contribution overlaps with another line of interests linked with activist knowledge and the role of the civil society in conceptual development in ecological economics and political ecology (Martinez-Alier et al., 2014, 2011). In this line of interest, I am currently editing a special issue on mining conflicts and environmental justice for the journal Geoforum with Begum Özkaynak.

An introductory paper on the state of the art of the research on Degrowth was prepared with other co-editors of a special issue about this topic (Sekulova et al., 2013). A paper on the costs of climate change through the lenses of the ecosystem service approach (Rodríguez-Labajos, 2013) was produced in the context of a collaboration as contributing author for the chapter on impacts of climate change on terrestrial and inland water systems (Scholes et al., 2014) of the last report of the International Panel on Climate Change (IPCC) .

Logically all these topics are not integrated within this PhD thesis, since the nature of the different contributions is very diverse, both empirically and conceptually. However, two threads connect them with the contents of this dissertation. First, there is an interest to tackle the drivers of major environmental problems rather than just planning responses from the observation of impacts. Second, there is awareness of the multi-dimensional nature of environmental phenomena, the analysis of which benefits from approaches that are open to integrate multiple views and languages (such as scenario development, multi-criteria evaluation or the ecosystem service approach).

Therefore, I am grateful to the many co-authors of these papers and their reviewers. More in relation with the direct developments of the thesis, comments by many researchers from universities and research institutes are gratefully acknowledged: Bill Cunin (University of Leeds), Laura Maxim (Centre National de la Recherche Scientifique), Ines Omann (Helmholtz Centre for Environmental Research), Narcís Prat (University of Barcelona), Kaja Peterson (Stockholm Environment Institute), Joachim

Spangenberg (Sustainable Europe Research Institute Germany e.V) and Mariana Walter (ICTA-UAB). Special thanks are given to Katherine Farrell (Humboldt-Universität zu Berlin) and Nicolás Kosoy (McGill University) for valuable comments that became crucially insightful during the framing of the dissertation.

Regarding the funding of the research activities, the ICTA-UAB group on the socio-economics of biological invasions was funded by the EC within the FP 6 Integrated Project 'ALARM' (COCE-CT-2003-506675). During the early stage of my research, I benefited from the training action Marie Curie in the Centre for Biodiversity and Conservation at the University of Leeds. Besides financial support, I owe to these initiatives the opportunity of exchanging opinions with scientific experts in the field of invasion biology. I want to thank institutional support and funding from the Catalan Water Agency and financial support from the Spanish Ministry of the Environment in Research and Development (R+D) Project No. 072/SGTB/2007/1.1. The exchange of opinions and information with all the partners of this R+D project is gratefully acknowledged (Institut de Recerca i Tecnologia Agroalimentàries, Universitat de Barcelona, Universitat Autònoma de Barcelona, Grup de Natura Freixe, Fundació Nova Cultura de l'Aigua). Of course, the contents could not have been developed without the generous involvement of many interviewees, surveyees and participant to workshops during the field research activities.

Working in academic tasks, one does not only learn as a student, but also when the moment arrives to help others to develop their own research initiatives. During these years of preparing the thesis I supervised three undergraduate dissertations for Environmental Sciences (by Samanta Benaiges, Núria Julve and Clara Sisteré), and five master dissertations (Nancy Arizpe, Kristofer Ditmer, Eloi Puigdollers, Clara Solé, Bianca Tillinger). Currently, I guide a PhD researcher (Dídac Jordà), who may become my first formal PhD student. To all them I express my most sincere thanks for what I have learned from our collaboration.

Last, but of course not least, I thank my two supervisors, Joan Martínez-Alier and Sigrid Stagl for accompanying the research process during these years.

Introduction

Invasive alien species (IAS) are the second most important threat to global biodiversity loss, after land use change (Sala et al., 1999; Schmitz and Simberloff, 1997), particularly in freshwater ecosystems (García-Berthou et al., 2005). Building on an long-lasting terminological deliberation (Blackburn et al., 2011; Colautti and MacIsaac, 2004; Pyšek and Richardson, 2010), invasive species are defined as species that have overcome geographic or reproductive barriers and threaten ecosystems, habitats or species with economic and/or environmental harm.

Due to these adverse effects the topic has become a focus of environmental policy concern (CBD, 1992: Art.8(h)). Aware of the alarming scientific scenarios regarding biological invasions in Europe (Hulme et al., 2009), the European Commission published a Communication describing the policy options in response to this threat (EC, 2008). The ensuing key priorities and components for an EU Strategy on IAS are already devised (Shine et al., 2010) and the proposal for a common EU legislation to address invasive alien species is under development (EC-Environment, 2014; European Parliament, 2014a).

As management of IAS becomes a main concern of biodiversity-related policies, other sectoral policies with strong cross-cutting implications also get increasingly influenced by this issue. Water management is one of them. This thesis aims at making a contribution in the interrelated matters of water management and invasive species policies, paying particular attention to the role of scientific support to management. With this in mind, this introduction outlines the research issues and framework.

Aquatic invasive species and water management

Aquatic ecosystems cover around 72% of the Earth's surface and generate roughly 38% of its net primary production (NPP). Within this realm, freshwater ecosystems (FWE) – wetlands, lakes and rivers – are a small part, with 0.9% of the Earth's surface producing less than 4% of the world's NPP (**Table 1**).

Table 1 Area and net primary production of aquatic ecosystems within major ecosystem types

Source: Based on data from Ehrlich et al., 1977: 132.

	Ecosystem type	Area		Total NPP	
		10^6 Km2	%	10^9 Mt C / yr	%
(A)	**Total continental**	**149**	***29,2***	**48,3**	***65,9***
(B)	Total freshwater	4,5	*0,9*	2,8	*3,8*
	Swamp and marsh	2	*0,4*	2,2	*3,0*
	Lake and stream	2,5	*0,5*	0,6	*0,8*
(C)	**Total marine**	**361**	***70,8***	**24,9**	***34,0***
(D)	**Full total (A+C)**	510	*100*	73,2	*100*
(E)	Total aquatic (B+C)	365,5	*71,7*	27,7	*37,8*

Despite containing less than 0.009% of the total available water (Shiklomanov, 1993), the role of FWE is essential in terms of ecosystem services provision. Human wellbeing depends directly on them for fish and fibre availability, water supply (including irrigation), water purification, climate regulation, flood regulation, coastal protection and recreational opportunities (MA, 2005).

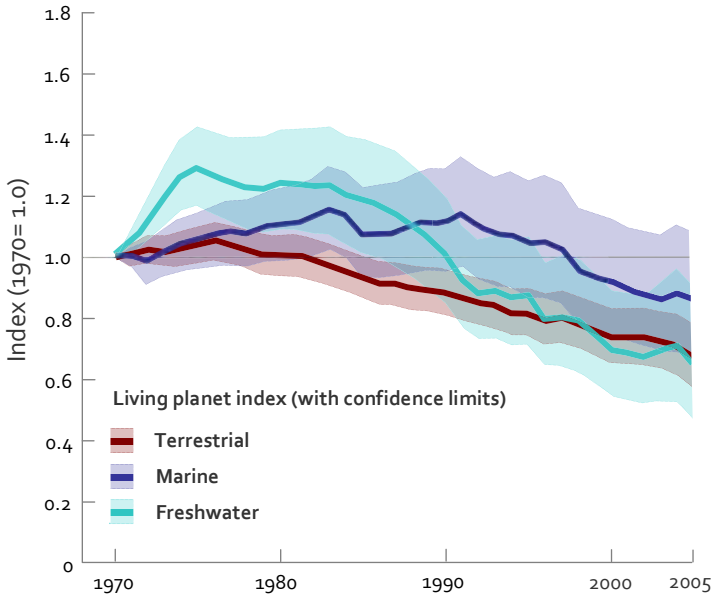
Some of these benefits may be estimated in terms of the associated cashflow. For instance, the last available survey by the U.S. Fish and Wildlife Service (2014) indicates that more than 33 million people take part in recreational fishing (inland and saltwater) in the United States, spending about USD 42 billion each year.

Some other benefits are rather related to the conditions for an effective achievement of basic human and environmental needs. Thus, due to the lack of healthy environments, 1–2 billion people worldwide suffer from null or declining access to fresh water (MA, 2005) despite the fact that safe water for human consumption was declared as human right by the UN General assembly in 2010 (UN, 2010).

In face of this, FWE deteriorate worldwide. The Living Planet Index (LPI) (WWF, 2010, 2008), one of the indicators tested by the CBD to track the state of biodiversity (Walpole et al., 2009), shows a generalised decline in the health of the planet ecosystems since the 1970s (**Fig. 1**). The freshwater LPI has decreased by 35 percent between 1970 and 2007, more than either the marine (25 percent) or terrestrial (24 percent) LPIs.

Fig. 1 Living Planet Index for major ecosystem types (1970-2005)

Source: WWF, 2008



This happens because FWE suffer from different pressures, and the proliferation of alien invasive species is a significant one, recognised as an emerging threat to water quality (Carr and Neary, 2008). Among the so-called 100 world's worst invasive alien species (Alowe et al., 2000), 21 are aquatic; either plants, invertebrates or fish. Up to 65 of such species in this list affect freshwater ecosystems like watercourses, lakes, wetlands, and river zones. The Directive 2000/60/EC establishing a framework for Community action in the field of water policy (the Water Framework Directive, WFD) points out invasive species as a biological pressure to the good ecological status of water bodies (EC, 2003). This is consistent with the increasing use of the term biological pollution to refer to aquatic invasive species, which sets the focus on them as a pressure to biological quality (Elliott, 2003).

Although this pressure is likely to increase, it is poorly studied (Strayer, 2010). The links between biological invasions and water quality have been reported in some striking cases, such as the noxious algal blooms following the establishment of black bass (*Micropterus* spp.) in Lake Atitlán, Guatemala (Fieser, 2009). The exploration of more systematic links, far from being understood yet, is inspiring a series of world conferences on Biological Invasions and Ecosystem Functioning (BIOLEF) and has reached the reference scientific literature. The journal Biological Invasions, in which only of 4 percent of all studies from 1999 to 2009 analysed the effect of invasive species on ecosystem functioning (23 percent of them in aquatic ecosystems), devoted a special issue to this topic in May 2011. While reporting these figures, the editors also summarise:

> "*One conclusion resulting from these published studies is that species additions will affect ecosystem functioning (e.g., productivity, biogeochemical cycles, decomposition) and biotic interactions (e.g. predator prey interactions, introductions of parasites and diseases), with some species also affecting human wellbeing. These effects will contribute to ecosystem functioning in complex ways and obviously will range from almost negligible to dramatic proportions* (Sousa et al., 2011: 1056)."

Together with this type of research needs in the domain of biosciences, there are also important knowledge gaps regarding impact analysis, communication or regulation, among others (Caffrey et al., 2014) that shape the effectiveness of management of aquatic bioinvasions. Comparative policy analysis to underpin integrated policies beyond specific cases is also highlighted as a research need (Simberloff et al., 2005). In face of this situation, it is worth to enquire about the nature of the scientific developments that are responding to the perceived research needs. This point is dealt with in the next section.

Science for alien species management: towards a reflexive model

Although scientific initiatives to support the management of bioinvasions may differ at some specific points in their approaches, all of them accept as basic policy guideline the Convention on Biological Diversity (CBD, 2002). In there, a hierarchical approach dictates a policy of prevention under the wide precautionary approach (Gregory and Long, 2009; Wittenberg and Cock, 2001). This is due to the fact that offensive responses against invasions (like eradication and control) are difficult and expensive – often unaffordable – once the species is established (McConnachie et al., 2012). Moreover, effects can be irreversible, like in case of extinction of native biota (Clavero and García-Berthou, 2005).

For this reason, many scientific efforts around invasive species focus on quantitative modelling (Gallardo et al., 2012; Worner and Gevrey, 2006) or semi-quantitative risk assessments (Andersen et al., 2004; Haugom et al., 2002; Verbrugge et al., 2010), with a proper account of impacts of invasion processes (Liu et al., 2011), in order to develop preventive policies. A quick search in any academic database will confirm that this is perhaps the most dynamic area of research regarding bioinvasion management nowadays. This risk approach is argued to be more reliable for short-term events, and more applicable for site-specific and/or species-specific management (Panov et al., 2009).

Yet the usefulness of quantitative forecasting methods applied to socio-ecological phenomena is hampered by the existence of non-linear key drivers and faster changes than the forecasting models can capture (Walker et al., 2002). The example of the intentional introduction of Nile perch (*Lates niloticus*) to Lake Victoria illustrates how such models may fail to capture the complexity of human-nature interactions regarding alien species (Chu et al., 2003). The interaction between factors makes each case unique, so generating good predictions may prove to be impractical (Heger and Trepl, 2003). The saying used to be that invasions are unpredictable in the way that earthquakes are (Williamson, 1999).

Moreover, there is not a unique perception of the invasion processes. Binimelis et al. (2007b) and Monterroso et al. (2010), for instance, analyse this issue for the invasion of the macrophyte *Hydrilla verticillata* in Guatemala. Managing bioinvasions needs to deal with what in management science has been qualified as a wicked problem (Rittel and Webber, 1973), being each case essentially unique and with changing constraints that are not always recognised.

However it is relevant to distinguish between 'natural phenomena' (most earthquakes) from 'natural phenomena with human roots' (biological invasions). While earthquakes would usually happen without human intervention (except perhaps in reservoirs), biological invasion would not, since they are human-mediated processes (Vitousek et al., 1997), as it will be elaborated further in the next section. In this

context, the reflexivity of human action in response to forecasts is fortunate, in a way. In the same way that humans are able to foresee excessive population growth or climate change, human behaviour can also be positioned in relation to actions against bioinvasions.

Regarding the management of IAS, the idea of reflexivity can be explored in two intertwined domains, governance and science. First, IAS management may look for directions in a model of *reflexive governance* that accounts for uncertainty and distributed power, as in the case of adaptative management (Voß and Bornemann, 2011). This approach emphasizes the value of collective learning processes (Brousseau et al., 2012), paying proper attention to management designs that develop defences against co-optation of alternatives by influential actors, and systematically considers political contexts and ongoing dynamics (Hendriks and Grin, 2007; Voß and Bornemann, 2011).

Little has been done to explore the potential for reflexive governance in the management of bioinvasions. Only two publications seem to mention reflexive or adaptative governance in the context of IAS management. Thus, Lang and Cooney (2009), recognising the role played by international trade in the spread of IAS, offer a framework for how the World Trade Organisation might respond to the uncertainties involved in the interpretation and application of the Sanitary and Phytosanitary Measures (the so called SPS Agreement). At a smaller scale, Hammer and Gilek (2012) report IAS as one of the five environmental problems in the Baltic Sea region that require better assessment-management interactions to move towards sustainable ecosystem governance. Without developing in detail the practical implications of the approach, both contributions call for forms of interaction between stakeholders involved and continuous review of the measures taken.

In this context, one may ask: which kind of scientific development is consistent with this approach in the identification of 'early warning signals' to avoid potentially unwanted events as bioinvasions? And, once these signals are available, how is science participating in the different steps of the management cycle?

Williams and Grosholz (2008: 4), offering insights gained as scientific advisers of IAS eradication efforts, recognise that for this matter the communication between managers and scientists should not be a monologue of the latter:

> "*Many scientists are increasingly interested in contributing to management projects, beyond publishing in journals that busy managers have scarce time to read. Because the cultures and timelines for meaningful results for the two groups are so different, we hope* (…) [to] *provide a perspective that might be useful as scientists head into the management arena. For example, familiarity with the regulatory framework for management can help scientists communicate better with their manager colleagues.*"

The concern prudently expressed by these authors mirrors several approaches who call for a democratisation of knowledge for scientific advice. The most radical one is post-normal science, which calls for a fundamental democratisation of expertise (Funtowicz and Ravetz, 1990; Ravetz, 1971), in opposition to the 'normal science' – reliant on the positivist paradigm and a linear model of innovation (Kuhn, 1970). Scientific debates regarding climate change (Beck, 2011) or basic health research (Crow, 2011) are examples of this paradigmatic tension. With enormous influence in ecological economics (Funtowicz and Ravetz, 1994), the implementation of the post-normal science concept enables the differentiation among the conflicting perspectives (fact- and value-based) in wicked problems (Farrell, 2011).

Similarly, other perspectives call for an engaged scholarship – rooted in Boyer (1996)'s 'scholarship of engagement' – where academics learn to listen public concerns in the organisation of their science

agendas. An example would be the practice of an engaged political ecology that goes outside the conference circuit to bind the outcomes of research with necessary societal transformations (Walker, 2006). In a similar vein, "*a model of science that embraces not detachment but engagement as the road to knowledge*" has been branded by Burawoy (2009:20) as a *reflexive model of science*. This model entails several principles among which intervention in social situation and the continual improvement of *existing* theory play a fundamental role (Burawoy, 2009: 68). Note that this approach detaches itself from Grounded Theory (Glaser and Strauss, 1967) although they both clearly share the use of inductive reasoning.

Without elaborating here a comparison between approaches, the main difference between the 'post-normal' and the 'engaged or reflexive' approaches to science seems to rely on the control of the research agenda, which in the latter clearly remains in the hands of scientists for the sake of the rigour of disciplinary expertise. This view is favoured by practitioners of science for policy advice aiming at balancing reliability and social robustness of scientific work. For instance, though defending the distinction between science, policy and morals, and the respect for free scientific enquiry, Helga Nowotny, former President of the European Research Council, declares in relation to the establishment of research questions:

> "*Problem choices, if they are to have an impact, must become institutionalised, contextualised, embedded and nurtured in a collective problem space. It needs to be reconfigured from time to time. This is, if you want, the normative side of the collective problem space* (Nowotny and Leroy, 2009: 63)*.*"

With this in mind, and due to perceived similarities between the cases presented by Burowoy and the ethnographic experience of the author of the thesis, the dissertation frames itself within the scope of the reflexive model of science at both levels. On the one hand, it is used as an epistemological and practical underpinning upon which the research questions and methods are based. On the other hand, the outcome of the dissertation aims at outlining a set of recommendations that bring together scientific developments and the management decision processes in relation to aquatic bioinvasions at the regional level.

Human dimensions of biological invasions and the DPSIR framework

As with other components of global change, biological invasions are human-induced processes (Vitousek et al., 1997). Human involvement in biological invasions has been structured following four dimensions: history, causes, consequences and responses to IAS (McNeely, 2001). That is similar to the DPSIR (Driving forces – Pressure – State – Impact – Response) model, which has been suggested for examining complex interactions between society and the environment (EEA, 2014). The causal chain assumed by the model links socioeconomic processes playing as driving forces (D) that induce pressures (P) on the environment and thus trigger changes in its state (S). As a consequence of the new environmental states the social system suffers impacts (I) that generate societal responses (R).

How has the DPSIR framework been used in the past to characterise biological invasions? Two possible uses can be found in the literature depending on whether the invasion modifies an entity whose state is of interest (e.g. biodiversity, ecosystems), or bionvasions themselves are the focal issue. On the one hand, *processes linked to the invasion become indicators of the different DPSIR components*, as it can be observed in the examples collected in

Table 2.

Table 2 Invasive species as DPSIR indicators

Source	Indicator	Policy issue	Category
MEA (2005)	Alien invasive species	Biodiversity loss and change in ecosystem services	Driver
EEA (2010)	Trends in aquaculture production, and newly introduced cultured and associated species in European Seas	Is the deterioration of aquatic ecosystems and habitats prevented?	Driver
	Invasive alien species in Europe	Biodiversity	Pressure
	Non-indigenous species in rivers and lakes	Is good surface water ecological status being achieved and deterioration of aquatic ecosystems and habitats prevented?	Impact
EC (2003)	Introduction of alien species	Biological quality in water bodies	Pressure
Cardoso and Free (2008)	Abundance and distribution of alien species		State
CBD (2002)	Alien invasive species	Biodiversity loss	Pressure
DEAT (1999)	Alien invasive plants and forest plantations	Terrestrial and freshwater ecosystems	Pressure
DEAT (2006)	Invasive alien species	Biodiversity and ecosystems	Pressure
	Total economic losses of ecosystem services due to invasive alien species	Biodiversity and ecosystems	State
	Contribution to job creation in the eradication of alien species	Biodiversity and ecosystems	Response

Thus, IAS are often mentioned as direct drivers causing biodiversity loss by the Millennium Ecosystem Assessment (2005). It is worth pointing out that the distinction between indirect drivers and direct drivers made by the MA is similar to that of driving forces and pressures *sensu* EEA. IS may be then seen as one of the pressures on biological diversity (CBD, 2002) driven by factors such as international trade, climate change or increased tourist flows. As mentioned above, the WFD also points to the presence of alien species in aquatic ecosystems as a pressure on biological quality (EC, 2003).

The South African Department of Environmental Affairs and Tourism (DEAT, 1999) included initially IS – specifically, 'alien invasive plants and forest plantations' – as pressures on terrestrial and freshwater ecosystems. The revised version of this report (DEAT, 2006) proposed the use of indicators related to biological invasions both to illustrate pressures on and state of biodiversity and ecosystems, as well as responses to control such pressures. Finally, the European Environment Agency (EEA) (2014b) refers to IS as either drivers, pressure, or impact in different biodiversity-related issues.

On the other hand, *the DPSIR framework has been used to examine the process of invasion itself as a policy issue*. Four examples can be mentioned in this respect. First, the advisory group supporting the UK Biodiversity Action Plan uses the DPSIR framework to present the research priorities and progress on the theme of non-native species (UK Biodiversity Partnership Standing Committee, 2003). Second, Elliott (2003) employs the DPSIR approach for discussing the parallels between chemical and biological 'pollutants' (referring to IS) in marine and estuarine areas. Third, the South African reporting scheme mentioned above also pondered the issue 'Invasive alien organisms' as a policy issue during the phase of indicators selection (Le Maitre et al., 2002).

Finally, Hulme (2008) drew upon the discussions of the Integrated Project ALARM (GOCE-CT-2003-506675) to organise information about biological invasions in Europe using the DPSIR categories. This study was a first attempt to apply empirical data to illustrate the DPSIR causal link for understanding biological invasions. It is mainly focused on the ecological dimensions of the invasion although there is a

clear linkage from the identified driving forces and responses to the socio-economic dimension. While the author makes a distinction between different levels of response, he does not distinguish levels of driving forces, making them equivalent to an aggregation of pathways.

This second use of the DPSIR categories allows going one step beyond in the recognition of the socio-economic dimensions of biological invasions, a human-induced phenomenon traditionally analysed from the perspective of the natural sciences. Still, the studies mentioned above lack a systematic examination of the relevant stakeholders playing a role in each one of the categories.

The above review also shows that the use of the DPSIR framework in the invasion literature has been heterogeneous. Not only the entity whose state is of interest is diverse, but also the definition of the DPSIR terms is implicit rather than explicitly developed. As a result, they are not used in a precise way.

From here, it is possible to identify two keys for the successful application of the DPSIR framework:

- a demarcation of the policy issue at stake (e.g. conservation of biodiversity) or a clear-cut definition of the DPSIR terms if the policy issue is the invasion process itself; and
- an identification of agency, i.e. who are the actors that play a role in the process (e.g. driving changes or experiencing impacts of the invasion).

As we wrote in the conclusions of the ALARM project, while being appropriate for enhancing communication, the DPSIR scheme needs improvement as an analytical tool (Maxim et al., 2009). In order to boost the discussion of biological invasions as a policy issue, the corresponding definitions of DPSIR categories are proposed next, consistent with those by Maxim and the literature of the invasion biology, keeping an explicitly socio-economic focus.

These definitions are presented in **Box 1**, and they include a link with some sections of the thesis where they are employed or where a particular concept is elaborated on. A graphic representation of the DPSIR approach consistent with these definitions is presented in **Fig. 2** (page 26), which also serves another purpose by outlining the conceptual flow of the thesis along its different chapters, and their interactions.

Box 1 Reviewed definition of the DPSIR components for biological invasions

Driving force

The terms 'vector', 'pathway' and 'driving force' are often used synonymously, although they are not equivalent. The term vector has a wide use in invasion ecology referring to dispersal agents relocating propagules to new environments. Herein vectors refer to living hosts (plants or animals) carrying alien species. Thus, analysing the movement of the vectors can unveil the drivers for unintentional introductions.

Pathways are ways of introduction or release of a new species in the ecosystems, i.e. recurrent routes of invasion directly related to the species transport (Simberloff, 2005). Hulme et al. (2008) distinguish six categories of pathways according to the gradient of human intent. Analysing patterns in pathways helps to identify driving forces, and systemic changes that lead to the establishment or further spread of the species. Ecologists use the term invasibility to denote this vulnerability (Lonsdale, 1999), that is, the conditions that make an environment susceptible to invasion processes. Socio-economic drivers (land use change, construction of roads or canals) may open new pathways, increasing bioinvasion success. Although significant pathways of the past may be inoperative in current social or technological conditions (US OTA, 1993), their analysis provides information about the accumulation of individuals and propagule banks.

As a synthesis, the term driving forces refers to the changes in the social, economic or institutional domains that trigger the introduction, release, spread and establishment of invasive species. Socio-economic driving forces of biological invasions operate at different levels, an idea explored by Le Maitre et al. (2004) for the case of plant invasions in South Africa. **Chapter 2** of this thesis expands on such multi-level character of driving forces.

Pressure

Pressures are consequences on the biological-ecological domain in response to the human activities that play as driving forces of biological invasions. Pressures have the potential to influence the use of resources or the intensity or frequency of disturbances, since they are associated to enhanced processes of introduction, release and establishment of IS.

State

State indicators give a picture of the current condition of the invasion process itself, in biological terms. For this reason, depending on the accepted definition of biological invasion, state indicators may illustrate IS richness, abundance, reproductive status, density or distribution in absolute or relative terms. **Section 4.2** includes a discussion about the use of biopollution indices to assess state, in the context of ecological quality of water ecosystems.

Impact

Binimelis et al. (2007a) define socio-economic impacts as socially perceived changes in the ecosystems caused by IAS. Accordingly, impacts can be organized through the categories of ecosystem services (ES). The emphasis put on the human perception helps to explain the scarce social awareness about alien species that cause high ecological distress but limited socio-economic effect. Apart from impacts on ES, biological invasions affect human-made goods and services. There is also a distinction between direct impacts of invasions and indirect or 'second order' impacts (see Omann et al., 2009) that stem from the implementation of responses to the invasions. This is pertinent to explain stakeholders' perceptions about the outcome of the invasions. **Chapter 3** addresses this dimension based on secondary data and specific case studies.

Response

Ensuing from the societal perception of impacts, groups or individuals respond diversely to the invasion. Similarly to climate change policies, Perrings et al. (2002) classify the responses to biological invasions as either mitigation or adaptation. By reducing the likelihood of species' establishment or spread, mitigation aims to prevent the invasion, whereas adaptation entails changes needed deal with IAS impacts once the invasion has taken place. The CBD (2002) suggests a hierarchical approach comprising actions for prevention, early detection, eradication and control during the successive stages of the invasion process, under the guideline of the precautionary principle. Even spontaneous collapse has been presented as an argument to consider 'do-nothing' as response option (Simberloff and Gibbons, 2004). The choice between mitigation and adaptation depends on both the stage of the invasion process when the decision is taken, and the perceived possibilities for predicting and controlling the dynamics of the system (Perrings, 2005). **Chapters 4** and **5** focus on methodologies to prepare responses in face of uncertainty and on a set of recommendations for integrated response, in the case of aquatic bioinvasions in Catalonia.

Methodological approach

Objectives and research questions

The purpose of this dissertation is to document and explain the socioeconomic elements of bioinvasions in aquatic ecosystems in Catalonia and how, in this context, scientific work is used to shed light into knowledge gaps for management. The overall objectives of the thesis are:

i. To explore and assess approaches for addressing the knowledge gaps regarding driving forces, impacts and the preparation of responses to aquatic bioinvasions.

ii. To reveal how management, the scientific activities supporting management, and the different agencies involved interact regarding the socioeconomic elements of aquatic bioinvasions.

iii. To propose guidelines for management of alien species in aquatic ecosystems in Catalonia that take into account the knowledge gaps along the invasion process.

In order to achieve these objectives the research focuses on five key issues and groups of research questions that are progressively addressed in different parts of the dissertation (**Table 3**).

Focus of interest regarding aquatic alien species

In the thesis the terms Invasive Alien Species (IAS) and Invasive Species (IS) will be used interchangeably and will refer those Alien Species (AS) that are associated with socioeconomic or environmental harm. The term AS will be use to designate the opposite to native species, referring to a geographic boundary. AS will be used interchangeably with the terms exotic species and introduced species, although the author is aware of the nuances that distinguish these terms.

In order to focus the discussion, the argumentation will be mostly based on cases of bioinvasions in the aquatic natural environment. There are also some AS spending part of their live cycle in aquatic environments but are mostly concentrated in urban areas (e.g. *Aedes albopictus*, tiger mosquito) or agricultural contexts (e.g. *Pomacea insularum*, apple snail). The management of these species involves authorities, policies and regulations beyond water management (e.g. local councils or agricultural actors). While these cases will appear along the text for underpinning some argumental lines, the dissertation is focused on bioinvasions directly related to water management in river ecosystems.

Table 3 Key issues, research questions and specific objectives in the chapters of the thesis

Ch	Key issue	Research question	Specific objective
1	State (or management context)	Which societal, environmental, scientific, normative and administrative conditions frame the management of alien species in the aquatic ecosystems of Catalonia? How did aquatic bioinvasions become a matter of environmental policy and management?	To provide empirical background for the argumentation developed in the rest of the dissertation, ensure reliability of the research project and validating the research relevance. To describe how management of aquatic species has become a matter of environmental policy and management in Catalonia, in particular in relation with the improvement of water quality, and how management and public perception have evolved over time. To unveil the socio-economic dimensions of specific IAS, and the different policy responses and social attitudes towards IAS, based on concrete case-studies.
2	Driving forces	Which driving forces of biological invasions operate at different levels of the formulation of policy measures? Which types of incomplete knowledge are related with the driving forces of damaging bioinvasions, like the zebra mussel? Which analytic methods, useful for the formulation of management measures, are consistent with such types of incomplete knowledge? What are the factors influencing establishment, perception of the impacts and the kind of response to the invasions of the zebra mussel and European catfish in the Ebro river? What are the generic forces driving the zebra mussel invasion in Catalonia? How do driving forces of aquatic bioinvasions relate to the concept of local agency?	To provide greater insight into driving forces and pressures on biological invasions expanding on the multi-level character of such processes To compile information about of driving forces in a post-invasion context (the Ebro River) to understand how the invasion of zebra mussel may percolate to other regions that are currently in a pre-invasion context To recognise policy measures that are coherent with different sources of uncertainty in the management of the zebra mussel invasion, in order to properly integrate them in the development of preventive measures To identify constituents of local agency and to evaluate agency capabilities for one of the analysed study areas.
3	Impacts	What are the impacts on ecosystem services of the IAS present in Catalonia? Which AS present in Catalonia are more directly related with impacts in water quality? What are the monetary impacts associated with the invasion of the zebra mussel in selected areas of Catalonia (in a post- and pre- invasion context)? Which attributes of AS impacts are relevant for management and what at are the implications for management-oriented assessment of impacts?	To overview notions on the assessment of the socioeconomic impacts of biological invasions, including a methodological framework to structure the information on IS impacts. To illustrate such framework with the example of aquatic species both at the EU and at the Catalan level, with particular attention to potential effects in water quality. To analyse the impacts of zebra mussel and European catfish in the Ebro and to estimate possible impacts of the zebra mussel invasion in a vulnerable area in the Ter River.
4	Preparation of responses a) Risk assessment	What is the state of the art in the use of risk assessment tools regarding biological invasions in general and in Catalonia? What are the needs and challenges for further development of risk assessment methods in the field of bioinvasions? What are the desirable attributes of risk assessment tools for practical decisions regarding the management of AS?	To review the use of risk assessment as a management tool in the case of exotic species in aquatic ecosystems in Catalonia and to assess its usefulness for guiding management measures.
	b) Bioconta-mination and biopollution (BC&BP)	Can BC&BP indices proposed in the literature be applicable in Catalonia with information available from the routine monitoring programmes? Are the BC&BP indices actually state indicators, i.e. do their results respond to indicators of pressures to the water bodies? Are the BC&BP indices redundant with the existing indicators of state for a given biological element?	To test existing BC&BP indices, assessing their correlation with pressures in the water bodies and their possible redundancy with indicators used to evaluate biological quality of the water bodies
	c) Scenarios	How can scenarios support management in pre- and post- invasion contexts? How stakeholders at different scales are positioned in relation to the scenarios and how this can be approached from a methodological point of view?	To test different approaches to scenario development in the case of biological invasions. To develop scenarios about the invasions of the zebra mussel and the European catfish in a post invasion context (the Ebro River), and about the invasion of the zebra mussel in a pre-invasion context (the Ter River). To propose a strategy of interaction between scenarios at different scales.
5	Responses	Which policy recommendations can be derived from the findings of the thesis?	To synthesise the knowledge achieved from writing the dissertation in the form of general prescriptions

Research methods

In order to achieve the specific objectives listed in **Table 3,** a variety of methods were used. An overview of these methods is presented in **Table 4**. The details for the implementation of each one (including the selection of materials, data and/or participants), the combination of methods for the different research phases, and the relation with specific research questions and objectives is clarified in the corresponding chapters.

Table 4 Key issues, research questions and specific objectives in the chapters of the thesis

Research phase	Activity	Chapter			
		1	2	3	4
Data gathering	*Collection of secondary data*				
	Literature review	●	●	●	●
	Hemerographic			●	
	Documentation (archives & official minutes; regulations; fora & social networks)	●			
	Databases (e.g., DAISIE; FishBase; Exoaqua; IBICAT; ExoAqua)			●	●
	Detached collection of primary data				
	Direct observation	●		●	
	In-depth interviews (semi-structured)		●		
	Focus groups and workshops		●		●
	Survey			●	
	Engaged collection of primary data				
	Ethnographic – participatory observation	●	●		
	Interviews and meetings (unstructured / management oriented)	●		●	●
	Management-oriented field work (e.g., informative campaigns, training courses)	●			
	Organisation / participation workshops		●		●
Data organisation	*Organising approaches*				
	DPSIR	●	●	●	●
	Multi-case study approach / In depth (extended) case study	●			●
	Levels of reflexive governance		●		
	Ecosystem service approach			●	
	Tools				
	Ad hoc data bases (MS Excel; MS Access)			●	●
	GIS (ArcGIS)	●			
Analysis	*Qualitative / hybrid*				
	Historical data series / chronologies	●			
	Participatory system dynamics approach		●		
	Comparative case study		●		
	Scenario development (participatory, analytic)			●	●
	Quantitative				
	Descriptive statistics: summary statistics (e.g., central tendency, frequency distribution); visual graphs (e.g., box plot, radar chart)	●		●	
	Monetary valuation (estimates of damage costs / control costs)			●	
	Calculation of biopollution indices				●
	Correlation analysis				●
	Probability and conditional probability				●

All along, contextual information was obtained though *secondary sources* (geographic and statistic databases, specialized webpages, scientific journals, reports and press releases). In this research, the systematization of non-academic literature has been a must, in a context with little socio-economic scientific production, given the relative novelty of the issue.

However, the fundamental contribution of this dissertation is the application of several qualitative participatory methods to the study of aquatic bioinvasions, which can be organized in two different phases. During the first phase, the research activities were aimed at interpreting the course of events, giving an insight into the stakeholders' perspectives about the socio-economic and technical traits of the invasion process. During this stage, that can be qualified as a *detached collection of primary data*, several research techniques were applied.

1. Direct observation (keeping field journals, organizing photographic and video galleries and completing field sheets about specific topics of interest).
2. In-depth Interviews with local and regional authorities, watershed authorities, environmental organizations, scientist, anglers and angling societies, irrigation societies, tourism managers and representatives of the energy sector. Data from conversational interviews was included in the field journals, while in-depth structured or semi-structured interviews were transcribed close to verbatim and afterwards analysed. Interviews allowed:
    a. To obtain the narrative under the experience of the interviewees about the invasion processes. Description of facts, opinions and assumptions offered by the interviewees were cross-checked to elicit internal consistency and detect (dis)agreements on facts and divergent interests around IAS.
    b. To select key participants for other participatory research activities and to sound their opinion out about the utility of such activities. This afterwards helped to pursue the appropriate social framing of the research and to adapt the progress of the project to stakeholders' expectations.
3. Focus groups and workshops were organized to promote group discussions and deliberation around the biological invasions in the Ebro. Specifically, this phase of the research involved two kinds of workshops, an expert meeting with international participation in February of 2005 and a scenario workshop in September 2005. Both meetings were held at Flix each with the participation of 25-30 local and regional stakeholders. The scenario workshop integrated different activities (brainstorming, focus groups; both in plenary and in smaller discussion groups) adapting the methodology of the IDON Scenario Thinking (Galt et al., 1997).
4. A survey for the quantification of impacts of the zebra mussel in the colonised area of the Ebro River was undertaken during 2006-2007.

This first phase of research, which started in late 2004 with the ALARM project, did not aim at directly involving the analysts with the evolution of the case. The workshops were recognized by the stakeholders as events that contributed to the change of their knowledge system beyond their own initiatives. Yet, the intention of the research team was not to guide a change process but rather to observe and analyse it.

At the beginning of 2006, the first research results caught the interest of one of the involved regional administrations, offering to the author the opportunity to become directly involved in the course of action through a collaboration with the regional administration in charge of water management. Since 2006 and until 2010, a phase of *engaged collection of primary data* took place.

The research approach of this phase was characterised by ethnographic or participant observation (Adams, 2012; Angrosino, 2007). It entailed detailed exploration of the socio-environmental aspects of IAS in Catalonia, through a complete involvement in the pursuit of practical goals, including the organisation of field trips, working meetings, and workshops (including training activities) with different types of regional and local stakeholders. This approach recognises both the increased quality of knowledge production and the instrumental value of such production.

One of the advantages of participant observation has been to facilitate access to different sorts of participants beyond it is the accustomed in university research. The results presented in this thesis include formal and informal consultations with government officers (at the EU, national, regional, and local levels) in different areas (water management, nature protection, agriculture, planning, environmental surveillance, and forest fire control); with sport associations (anglers, motor boat holders, canoeists, water-skiers, marina managers), with national and international scientific experts, with environmental and educational NGOs; with representatives of the private industrial and energy sector, and with consultants in different methods of invasive species control.

The methods for the organisation of data involve both organising frameworks and tools to deliver data in formats that could be further analysed. Organising frameworks, such as the ES approach or a scheme for levels of reflexive governance, have been refined and adapted to the specific contexts to be applied. In fact, this has been a concrete materialisation of the reflexive approach adopted in the thesis.

Moreover, part of the organising frameworks have been based on an inductive approach. A variety of raw data was condensed into a summary format and emerging ad hoc categories and links appear according to the needs of reasoning, thus contributing to conceptual development. An example of this is the identification of relevant stages of the invasion process employed in the calculation of impacts of the zebra mussel and in the development of management scenarios.

Based on this, different qualitative and quantitative methods have been used to analyse data, thus responding the research questions. Qualitative methods, or hybrid methods using also some quantitative elements include, e.g., comparative case studies or scenario development, both analytic and participative. Quantitative methods encompass different techniques of descriptive statistics, correlation analysis and the calculation of conditional probabilities. Other quantitative methods employed involve the estimate of monetary costs related with the invasion of the zebra mussel in two study areas and the calculation of biocontamination and biopollution indices for rivers in Catalonia, based on fish species.

Thesis outline – Remembering *Rayuela*[1]

As mentioned above, the DPSIR framework is employed to structure contents in a way that truly reflects the reflexive nature of the management of IAS. Therefore, the chapters that follow explore in detail the different components of this framework thus enabling a comprehensive exploration of the different socioeconomic dimensions that are relevant for management.

- **Chapter 1** overviews the current context or *state* for the management of alien species in the aquatic ecosystems of Catalonia, both at the regional level and in two study areas (in the Ebro River and the

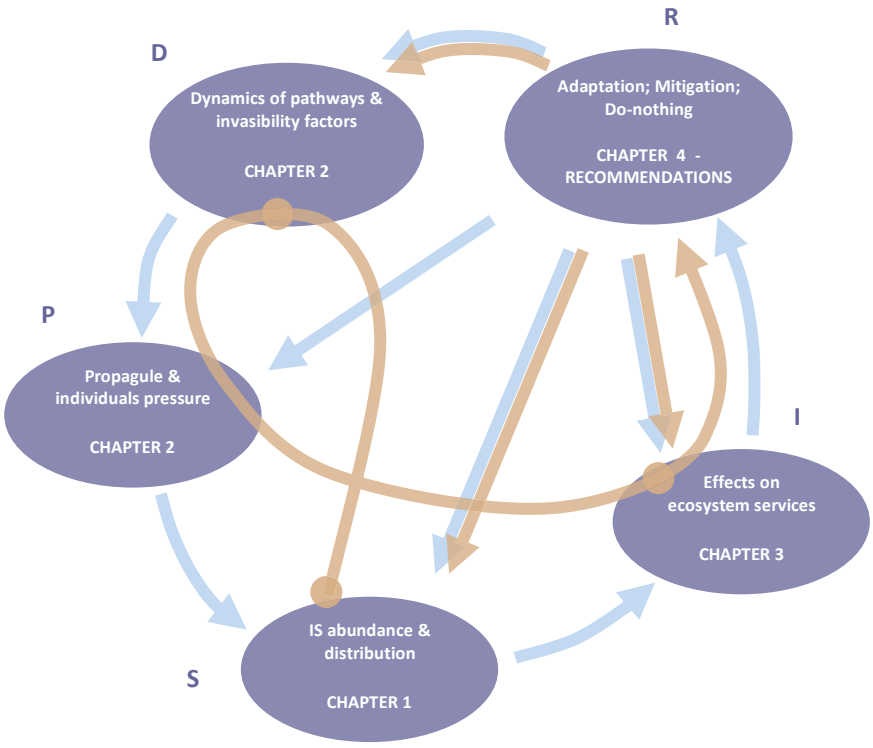
[1] *Rayuela* (Hopscotch, in English) is a novel by Argentine writer Julio Cortázar, where the main character tries to find a sense of order in the world's chaos. Cortázar introduced in this novel several literary innovations, being the most praised one a format that allows several sequences of reading (sequentially, eliding some chapters, as a collage of episodes, or trusting the reader with the construct of a new way of organising the contents).

Ter River). Several IAS are mentioned but the main focus is on *Dreissena polymorpha* (zebra mussel) and *Silurus glanis* (European catfish).

- **Chapter 2** analyses *driving forces* and *pressures* of biological invasions, expanding on the multi-level character of the invasion processes. Driving forces of the invasions in the study areas are analysed making use of participatory methods.
- **Chapter 3** contains various notions on the assessment of the socioeconomic *impacts* of biological invasions and examines their relation with management. The chapter contains an estimate of actual and potential impacts of the invasion of the zebra mussel in the two study areas.
- **Chapter 4** examines in-depth diverse research tools and approaches to address uncertainties in the preparation of *responses* to bioinvasions. These approaches encompass risk analysis, the calculation of biocontamination and biopollution indices and scenario development.
- **Chapter 5** provides an articulated set of recommendations to organise *responses* to aquatic bioinvasions. This chapter, informed by insights from the rest of the dissertation, is presented as an action-oriented conclusion, or contribution to the theory of IAS management based on a reflexive model of science.

The organisation of contents, consistent with the adopted approach, is not linear. There are feedbacks between sections analysing each component, as there are in the problem at hand. Main loops will emerge, for instance, between the analysis of driving forces (**Chapter 2**) and scenario development (a part of **Chapter 4**), and between the scenario development and the assessment of impacts (**Chapter 3**). **Fig. 2** shows this situation. Blue arrows indicate the traditional interlinks in the DPSIR approach. Light brown arrows indicate the organisation sequence in this thesis, with dialogues between different chapters.

Fig. 2 DPSIR framework as the conceptual flow of the thesis



Despite the interactions between sections, each chapter has been prepared in a way that presents a self-contained set of contents. With the aim of making the reading of the thesis not only a scientific but also an aesthetic exercise, three alternative ways of reading are suggested. First, the dissertation can be read from chapter 1 to 5. This entails a departure from the traditional DPSIR, as the presentation of contents starts here from an overview of the *state* in the issue at hand. This has been motivated by the need of setting the stage and providing empirical evidence for the rest of the chapters. The rest of the thesis follows the traditional sequence, although not all possible interlinks in the original DPSIR scheme are explored in depth. Second, the chapters can be read following the traditional DPSIR chain, which would mean to swap the order of **Chapter 1** and **Chapter 2**. Third, the reader may decide to follow the connections to the different sections indicated in the text and, once a given interdependence is clarified, come back to the original threat in the argumentation.

Of course, the reader is free to construct a different way of reading the chapters, although this is recommended only after a first reading of the thesis has been completed. The author is well aware of the distance between her own literary skills and Cortázar's.

1 The issue at stake: alien species in Catalan aquatic ecosystems and their management

This purpose of this chapter is to provide empirical background for the rest of the dissertation. The idea is to get a picture of the current situation regarding the management of alien species in the aquatic ecosystems of Catalonia. This is done to ensure the reliability of the research process, but also to validate the research relevance, which has implications in a real world situation with repercussions in environmental management.

The information was obtained from multiple sources of evidence, to get as thorough an understanding of the state-of-the-art as possible. Most of such sources are qualitative (direct observation, participant observation and interviews). When available, scientific literature and official data have been used to underpin the explanation. Specific references are provided alongside the text.

The chapter is structured as follows. First a general overview of the state of knowledge about alien invasive species in Catalonia sets the stage to understand how this issue has become a matter of environmental policy and management. The next section illustrates how this management is shifting from addressing specific threats related with certain species to a more integrated concern about the state of the aquatic ecosystems under the Water Framework Directive (WFD). An explanation follows of the implications of this regulation for IAS and the way this has been implemented. The final section focuses on the cases of two aquatic species in two study areas within Catalonia.

1.1 Aquatic alien species in Catalonia

1.1.1 The rise of a socio-environmental issue

The combination of diverse and benign habitat conditions, millenary human-environment interactions and relatively high affluence make Catalonia (NE Iberian Peninsula) a good candidate region for bioinvasions. Within the Spanish territory, the areas with the highest level of plant invasion are in the NE coast (Gassó Pérez-Portabella, 2008; Pino et al., 2005). An analysis of plant species distribution show that, in this region, the habitats with a higher degree of invasion were the most disturbed ones (e.g. riparian) and those with more anthropogenic influence (e.g. agricultural and trampled) (Vilà et al., 2007).

Until recently, research on plant invasions in Catalonia was more developed than for other taxonomic groups, among them alien species in aquatic ecosystems. This is due to a remarkably long tradition in botany in the region, which allowed the gathering, organisation and exploitation of a great number of floristic records (Gassó Pérez-Portabella, 2008). The systematisation of information about alien species improved considerably in recent years, thanks to the Information System on Alien Species in Catalonia (EXOCAT) (Andreu et al., 2012).

In part, this effort builds upon the enhanced knowledge of invasions in aquatic ecosystems during the previous decade. In the region, research of aquatic ecosystems is very much influenced by the outstanding legacy of Professor Ramon Margalef (1919-2004) who trained several generations of ecologists, limnologists and oceanographers and had a major role in the popularization of ecological thinking (Ros, 2004). The foremost research groups on aquatic biology and ecology are at the University of Barcelona (UB), University of Girona (UdG), University of Lleida (UL), and Institute for Agro-food Research and Technology (IRTA). Talking about marine research, two centres must be mentioned, both linked to the Spanish Council for Scientific Research (CSIC): the Centre for Advanced Studies of Blanes (CEAB) and the Institute of Marine Sciences (ICM). Besides the academic arena, a variety of practitioners

and consultancy organisations have also built up a reputable expertise on this field for the trained specialists in Catalonia.

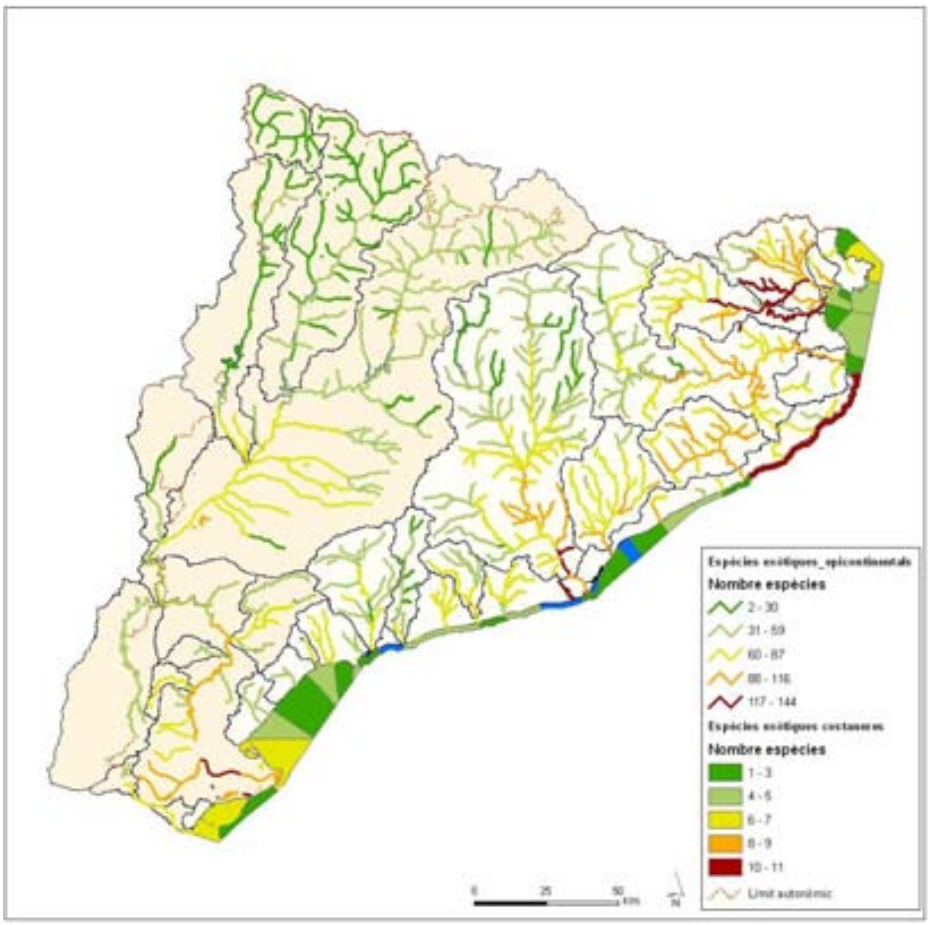
While improving the general knowledge on the biology and ecology of aquatic environments, a focus on alien species was developed by the diverse research groups. In this context, since 2009, the Catalan Water Agency commissioned the compilation of the existing information about the distribution of alien species in the aquatic ecosystems. The results were made available through the SI-ExoAqua (Information System about Alien Species in Aquatic Ecosystems) commissioned to the Centre for Ecological Research and Forestry Applications (CREAF) (Andreu et al., 2011). According to this data, there are ca 430 alien species of different taxonomic groups (algae, plants, invertebrates, fish, birds, amphibians, reptiles and mammals) in the Catalan Aquatic ecosystems (

Fig. 3). In October 2014, the information publically available maintains the same number of entries (Carolina Solà, pers. comm.).

Fig. 3

Alien species richness in the coastal and inland waters of Catalonia (Oct, 2014)

Source: Exoaqua



This depicts a problematic situation in two respects. On the one hand, it poses a **challenge for policies of biodiversity conservation** as the threat imposed by IAS for biodiversity is generally accepted in terms of policy making. On the other hand it creates a problem for **water protection and management** as there are complex links between the presence of IAS and the state of aquatic ecosystems communities both in inland and marine waters, and therefore, for water quality.

Both concerns, as argued in the following sections, also rely on regulatory basis, outlined next. In this way, what it might be a social alarm about the relation of humans with their environments and with some

particular elements of the non-human world, becomes also a practical problem of organising management responses with governmental involvement.

1.1.2 Normative and administrative framework for the management of aquatic bioinvasions

At the European level, where the proposal for a common EU legislation to address invasive alien species and protect biodiversity is still under development (EC-Environment, 2014; European Parliament, 2014a), there are already several regulations with implications on IS management. The Council Regulation (EC) 338/97 of 9 December 1996 on the protection of species of wild fauna and flora by regulating trade therein allows using species lists to prevent that wildlife be *threatened by trade or likely to be so threatened* (OJEC, 1997). Although in principle this regulation was conceived to prevent trade of the endangered species themselves, it opens the door to stricter measures at the Member State level in relation of trade of species threaten the domestic wild fauna and flora.Two different Directives related with the conservation of natural habitats and native wildlife (Directive 'Habitats' 92/43/CEE [OJEC, 1992]) and wild birds (Directive 'Birds' 2009/147/EC [OJEU, 2009]), respectively, urge the Member States to prevent the introduction of AIS into the natural environment.

More focused on AIS, the Council Regulation (EC) 708/2007 of 11 June 2007 concerning use of alien and locally absent species in aquaculture, and the Regulation (EU) 304/2011 of the European Parliament and the Council of 9 March 2011 amending Council Regulation (EC) 708/2007, established (and respectively amended) a framework governing aquaculture practices in relation to alien species to prevent their possible impact on aquatic habitats and organisms (OJEU, 2011, 2007). An interesting point in the latter Regulation is the introduction of an operational definition of the so-called 'closed aquaculture facilities'. This refers to facilities where the risk associated with AS – over all in relation to the potential for escape – can be managed, reducing it to acceptable levels. In such cases, some of the restrictions and requirements imposed by the Regulation would be exempted. This point will be taken up below, when the case of the introduction of the apple snail in Catalonia is explained.

At the Spanish level, the Law 42/2007, of Natural Heritage and Biodiversity (BOE, 2007) introduced both the creation of a National Catalogue of Alien Invasive Species and the ban to *possession, transport, traffic and trade* of any of the listed AIS, its propagules or its parts. The deployment of the Catalogue, regulated by the Royal Decree 1628/2011 (BOE, 2011), proved to be a challenging task. The restrictions foreseen in the law were very strict for the listed species, and many of the candidate species were either already established in the Spanish territory, associated with unintended transport, or had economic interest, such as species involved in gardening, aquaculture or recreational angling or hunting. A solution for this was to create a second list of *species with invasive potential*, which would guide preventive measures entailing less strict restrictions and would point to the next candidates to enter the more restrictive list in the Catalogue.

The process for selecting the species in the lists counted on inputs like the discussions of the open platform 'Spanish AIS Catalogue' (GEI, 2010). These kinds of amendments, expressing more stern views in relation to the need of tackling the AIS issue – summoning scientific evidence –, clashed with the economic interests on the management of certain alien species, particularly in relation to sports angling and hunting. In March 2012, a complaint promoted by the federation of anglers' associations led to the cautionary suspension of the Decree by the Supreme Court of Justice (BOE, 2012a) in relation to a fish species used in angling. The same month, three Autonomous Communities, Catalonia among them, also legally claimed that the Decree was against their right to exert exclusive responsibilities in the regulation and management of inland angling. The Spanish Council of Ministers resolved in favour of the claimants,

making several articles of the Decree inoperative in those regions (BOE, 2012). This was followed by a Manifesto supported by more than one hundred scientific societies, environmental NGOs and individual scientists concerned about the possible modification of the Decree and requesting the reinforcement of its measures (Comité Científico de SEO/BirdLife, 2012).

After this controversy, already during the period of the pro-business Spanish conservative government, a new Royal Decree 630/2013 (BOE, 2013) related with the deployment of the Catalogue replaced the former one. The basic modification was the substitution of the list of species with invasive potential by a non-binding list of species with higher invasiveness that should serve mainly for monitoring purposes. Species involved in sensitive economic sectors, such as agriculture and food (e.g., *Proclambarus clarkii*), and angling (e.g., *Oncorhynchus mykiss*) were left aside to be regulated by specific sectoral rules. Also, species involved in hunting (e.g. *Ammotragus lervia*) or the fur industry (e.g. *Neovison vison*), and in general species used in angling, were matter of particular exceptions in relation to the previous Decree.

At the regional level there are specific laws that respond to the objectives of the higher-scale levels. Thus, building on the Spanish Biodiversity Law, the Law 22/2009 of Sustainable Inland Fishing in Catalonia (DOGC, 2009) introduces measures to control alien fish and crayfish in aquatic ecosystems. To this end, the law establishes the ban to introduce alien species, and the obligation to kill the caught alien individuals, while it sets certain exceptions for both types of measures, related with the maintenance of angling practices. This point will be expanded in **Section 1.2**, on the case about fish invaders. Ensuing the Fishing Law, the annual angling programmes establish the specific conditions on where it is allowed to fish and which species can be caught (e.g., DOGC, 2014). So far, several AIS such as *Oncorhynchus mykiss*, *Carassius auratus* and *Cyprinus carpio* have been classified as 'fishing species' in these programmes, that is, they have the same consideration than native non-protected species for the purpose of angling, and their populations are not supposed to be controlled or eradicated.

Focussing on the norms related with water protection and management, there are two main directives of reference. On the one hand, the Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for action in the field of water policy (or Water Framework Directive, WFD) (OJEC, 2000) is an influential piece of regulation that urges the EU member states to achieve good qualitative and quantitative status of all water bodies (including inland and coastal marine waters) by 2015. The environmental objectives of the WFD, which was transposed to the Spanish national law in 2003 (BOE, 2003), may be jeopardised by the presence and abundance of AIS in aquatic ecosystems. This point will be considered in the **Section 1.3** of this chapter.

On the other hand, the Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishes a framework for action in the field of marine environmental policy (OJEU, 2008). It is also known as the Marine Strategy Framework Directive (MSFD) and it is very similar its structure to the WFD. The MSFD includes alien species altering the ecosystems as one of the eleven descriptors to determine a good environmental status of marine environments, which should be achieved by the year 2020 at the latest. Introduction of alien species is considered as a biological disturbance in the list of pressures and impacts on marine waters and ecosystems.

The various regulations seem to create common objectives in relation to AIS management, both regarding biodiversity conservation and water protection and management. Even so, there are several authorities in charge of implementing the different regulations in Catalonia. Currently, the responsibilities on environmental management in the natural environment are allocated in the regional General Directorate of Natural Environment and Biodiversity (DGMNB). This organism encompasses

several divisions in relation to topics for which the regional government holds full and exclusive responsibilities (such as hunting and inland fishing) and also to areas with shared responsibilities with the Spanish government (such as biodiversity conservation), according to the Statute of Autonomy of Catalonia (Boletín Oficial del Estado (BOE, 2006), after the assessment of the constitutionality by the Constitutional Court released on June 2010 (BOE, 2010).

Meanwhile, according to the water regulation (the Consolidated Water Law) (BOE, 2001), the watershed authorities are in charge of planning and management of activities in the public hydraulic domain, including some recreational activities such as navigation. Therefore, they are the public organisations in charge of implementing the mandate of the WFD.

In Catalonia there are two hydrographic regions from the point of view of water management and planning. On the one hand, the Internal Basins of Catalonia (IBC) are watersheds – eleven rivers and several coastal streams – whose area is totally within the boundaries of Catalonia. The IBC cover 16,423 km^2 (52 percent of the Catalan territory) and host 92 percent of the regional population. The watershed authority in the IBC is the Catalan Water Agency (ACA). On the other hand, the interregional basins (IB) are the Catalan sections of river basins that drain territories also outside Catalonia, in particular the Ebro, Garona and Xúquer. While the IB represent an area of 15,567 km^2 (48 percent of the Catalan territory), only 8 percent of the Catalan population is settled there (ACA, 2008). In the IB, there is more than one watershed authority (ACA at the regional level and another authority at the State level), with shared responsibilities in relation to water use, surveillance and other official proceedings. In the Ebro River, the authority for the granting of concessions is the Hydrological Confederation of the Ebro (CHE), depending on the Spanish Ministry of Agriculture, Food and Environment.

In summary, different water authorities and environment public bodies, among other public authorities, have legal mandates to tackle the issue of alien species, but they have also different agendas regarding a number of other issues. Their available budgets and formal responsibilities for different parts of the Catalan territory also differ. This map of different priorities, regulations and shared governmental responsibilities sets then the stage for the management of aquatic alien invasive species.

1.2 Management on practice - from charismatic species to the Water Framework Directive

This section contains instances illustrating the recent history of management of aquatic alien species in Catalonia. Paradigmatic cases of AIS management are used to show how, at the regional level, this management had been shifting from isolated responses to specific threats to a more integrated approach guided by the WFD.

1.2.1 From the killer alga to exotic macroalgae prevention or the power to focus public attention[2] [3]

[2] With acknowledgement to talks between 2007-20011 with: Marta Manzanera (ACA), Marina de Torres (ACA), Josep Vilagrasa (ACA), Enric Ballesteros (CEAB), Maria García-Gómez (CEAB) and Boris Weitzman (CEAB). The narrative is also enriched thanks to the participation in the Workshop on Alien Species and the EC Water Framework Directive (Ispra, June 17-18, 2009), the 2nd European Conference of Conservation Biology (Prague, September 1-5, 2009) and a working meeting ACA-CEAB on marine alien species (Blanes, November 3, 2010).

[3] Edward O. Wilson commenting on the book "Killer Algae" by Alexandre Meinesz (1999), translated by Daniel Simberloff, University of Chicago Press, 376p: "Once in a while a single example has *the power to focus public attention* on a serious problem, and this is one of them. The Caulerpa story (…) reads like a science-fiction horror story. It calls our attention to the growing worldwide problem of invasive species, the stealth destroyers of the environment."

The tropical green alga *Caulerpa taxifolia* was first detected in the Mediterranean Sea in 1984, released from the public aquarium in Monaco. By 1992, this ecologically damaging species – it threatens ailing *Posidonia oceanica* – had progressively been observed in France, Italy and also in Mallorca, Spain, where 250m^2 covered by the alga were discovered at an anchoring site (Meinesz et al., 2003, 2001).

In Barcelona, with local and regional governments then feverishly into the organisation of the Olympics, the news on the discovery of the alga in the Balearic Island made alarm bells ring. An early warning system was commissioned by the environmental authority, then in charge of coastal water quality monitoring (Josep Vilagrasa, pers. comm., 11/08/11). Considerable resources were applied to organise a sampling grid that included 126 stations along the Catalan coast, without the species being detected so far (Ballesteros et al., 2010, 2005, 2004).

C.taxifolia has spread along the western Mediterranean (**Fig. 4**) and it is often being mentioned as an instance of the crucial need for rapid response after early warning (Anderson, 2005; Genovesi, 2005). However, it is also argued as an example of the difference between a high invasiveness potential and a real invasive performance. In the Balearic Islands, after more than 20 years of its detection, the species has proved to be non aggressive and to have low colonisation capability, even spontaneously collapsing in one spot (E.Ballesteros, pers.comm., 18/06/09).

Fig. 4
Spread of *Caulerpa taxifolia* in the Mediterranean

Source: Meinesz et al. (2003), Rapport final. LEML publ. pp. 1-115

Although *C.taxifolia* was not detected in Catalonia, several years of systematic monitoring of the coast allowed observing previously undetected alien species. In 2006, the ACA decided to restructure the surveillance grid, so as to extend the early warning system to a broader set of alien macroalgae. The grid was organised around 60 stations to perform transects along a batimetric axe, in the areas deemed as more susceptible for the establishment, which where thoroughly characterised every two years (Ballesteros et al., 2010) (**Fig. 5**).

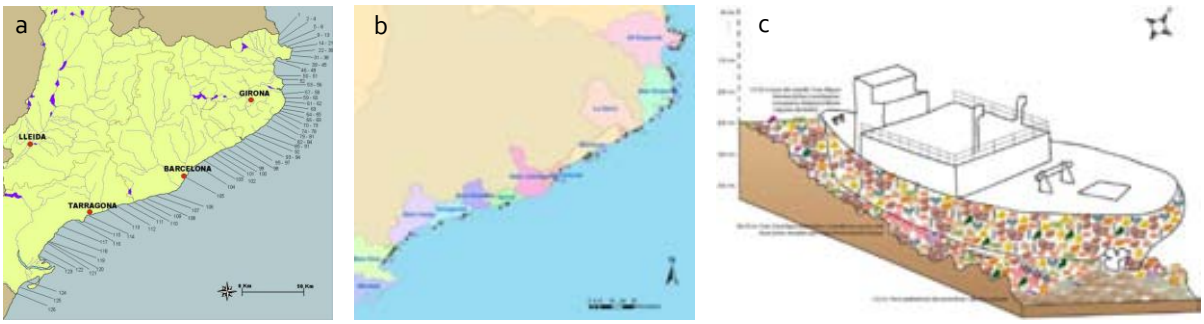


Fig. 5 a) Monitoring grid of C. taxifolia; b) Surveillance grid for alien macroalgae; c) sketch distribution of *Womersleyella setacea* in Palamòs, 2007

Source: Programme of exotic macroagae prevention (ACA/CEAB), Coord. Dr. Enric Ballesteros

As a result of this Programme of exotic macroalgae prevention several alien macroalgae (*Womersleyella setacea*, *Dictyota cyanoloma*, *Asparagopsis armata, Acrothamnion preisii*) were detected and subsequently surveilled. There is also monitoring of other introduced macroalgae, such as *Codium fragile*, or *Caulerpa racemosa* var. cylindracea, first detected in Vilanova i la Geltrú in 2009. Additionally, other alien species were registered during the monitoring procedures: e.g. *Oculina patagonica, Bursatella leachi*, *Percnongibess, Paraleucilla magnai, Microcosmus squamiger and Crassostrea gigas* (Ballesteros et al., 2010; **Fig. 6**). This, together with information form diverse research groups compiled by the ExoAqua information system verifies the presence of at least 23 marine alien species (algae, invertebrate or fish) a in the Catalan coastal waters (Marta Manzanera and Carolina Solà, pers. comm.).

This improved knowledge of the marine environment has meant two developments: a test of the biopollution levels of the area using the BPL index (Ballesteros et al., 2010: 90-97; see **Section 4.2** for an explanation of the index) and the inclusion of the marine invasive species within the programme of measures of the Catalan Water Plan, as it will be explained in **Section 1.3**.

Scientific name	*Asparagopsis armata*	*Dictyota cyanoloma*	*Womersleyella setacea*	*Acrothamnion preisii*	*Oculina patagonica*	*Percnon gibbesi*	*Bursatella leachi*
							
Year of detection	1920s, fist cited 1989	2005	2006	2010	1992	2003	2007
Where has it been detected?	Several points along the Costa Brava	Olympic port Barcelona Blanes Mataró Sitges	Palamós; St. Feliu ; Formigues Islands; Cadaqués; Cap de Creus; Cap Norfeu, Ullastres; Tossa Island	Palamós Torroella de Montgrí	Ebro delta Torredembarra	Prat del Llobregat - Port de Barcelona; Segur de Calafell; Salou; l'Ampolla.	St. Carles de la Ràpita Desenbocadura Riu Sènia, Badia del Fangar; Atmella de Mar

Fig. 6 Some alien species detected in Catalonia through the Programme of exotic macroalgae prevention

Source: ACA-CEAB. Pictures: Internet

For these activities, ACA relied on the scientific advice of the Centre for Advanced Studies of Blanes (CEAB), of the Spanish Council for Scientific Research (CSIC). Their collaboration is formally organised through several MOA outlining projects to assess seabed vulnerability and prevention of alien macroalgae (2004-2009) and to perform ecological quality monitoring through the characterisation of macroinvertebrate and algae communities (2008, 2008-2009, 2008-2012) (www.ceab.csic.es). The stability of this partnership has achieved a mutual trust and understanding of both the research and management needs. The two-ways information flow is fluid. Researchers of CEAB often accompany or represent officials of ACA to national or international meetings regarding matters (even loosely) linked to their joint projects.

The current challenges to reinforce action against alien invasive species in marine environments are two. First, there is a clear difficulty for carrying out species control. When a new species is detected, information to prevent the spread is promptly circulated through to a well-established communication network with coastal municipalities and other sea-related actors, mainly fishermen's associations. However, little is done to control the populations, regardless of the invasiveness of the species. This happened, for instance, when the highly invasive *Caulerpa racemosa* var. cylindracea was incidentally detected near Vilanova i la Geltrú. Technical and economic reasons were argued not to proceed in this respect. "*The sea makes you feel small*" says a government official, explaining how the lack of biophysical

barriers prevents the confinement of alien species in marine environments, making some invasions virulent without any possibility of control (Marta Manzanera, pers.com., 11/08/11).

Second, in contrast to fields were risks assessments of invasive species (RAIS) are well established (plants, and more recently, fish), a meagre number of publications indicate that RAIS of marine macroalgae is in its infancy (Nyberg and Wallentinus, 2005; Williams and Grosholz, 2008). Moreover, these works do not address the particularities of certain regions, such as the Mediterranean, where macroalgae invasions are an emerging threat. Scientific experts underline the difficulties of implementing RAIS, due to the generalized gaps in the existing datasets and the lack of biological and ecological knowledge of marine macroalgae. In face of that, expert assessment has been the best-suited way to get signals about the invasiveness of the species. To a certain extent, expert- based assessments are enough to support the current development of marine management. However, several reasons might justify the advance towards a protocolised approach to RAIS, including the need to explain the results of appraisals to non-scientific stakeholders, a more accurate guidance of preventive measures or the identification of information shortfalls and research needs.

1.2.2 The contentious management of fish invaders [4]

In inland waters, the knowledge of fish invaders is relatively better than for other aquatic *taxa* because fish have been systematically sampled as part of the monitoring routines for the assessment of biological quality in rivers, introduced by the BIORI protocol (ACA, 2006). According to the ExoAqua information system, which compiled this data together with other information provided by scientific experts in the field, there are more than 40 exotic fish species in the Catalan inland waters, 27 of which have been introduced as game or bait for angling. In particular, the introduction of alien fish through recreational angling is considered to be a global environmental degradation problem resulting in loss of biodiversity (Cambray, 2003) and has the Mediterranean basin as one of its hotspots (Tricarico, 2012).

There is a clear scientific and conservationist concern about this issue. In other regions of the world, alien fish have been positively related to disturbance intensity – involving local in-stream habitat and riparian degradation, water quality and surrounding land use –, to the extent of being suggested as reliable indicators of river (lack of) health (Kennard et al., 2005).

Indeed, the presence of certain alien species may have an effect on quality of inland waters. The drastic eradication of *Cyprinus carpio* (common carp) in Zóñar natural reserve (SW Spain) led to increase in water transparency and reduction of the anoxic layer below the surface waters, assessed one year after the eradication. Two years later, beneficial effects were observed in aquatic vegetation cover, and aquatic insects species and bird species richness (Fernández-Delgado, 2013). In Catalonia, the coordinator of the LIFE + project (LIFE08 NAT/E/000078) in the Banyoles Lake – a karst catchment within the Natura 2000 network, recognised as a Ramsar site since 2003 – explains that in *three* carps accidentally reached a wet

[4] With acknowledgement to talks between 2006-20011 with: Josep Escorihuela (formerly DGMN), Joel Capdevila (DGMN), Joan Vilaut (DGMN), Jordi Pagès (ACA), Carolina Solà (ACA), Nuno Caiola (IRTA), Adolf de Sostoa (UB), Emili García-Berthou (UdG), Carles Pla (UdG), Marc Ordeix (CERM), Alex de Juan (FCPEiC), Joan Lluis Bruna (FCPEiC), Josep Grau (AEMS-Rius amb vida) and the representatives of several local angling societies in Lleida, Tarragona and Barcelona provinces.

The narrative is also enriched by the participation in the 'Seminar on natural areas and biodiversity at the municipal level: sustainable management of angling and hunting', organised by Diputació de Barcelona (Montesquiu, 14/10/2010), with the presentation 'Fish restocking and alien species prevention in aquatic ecosystems' and the participation in the 2nd European Conference of Conservation Biology (Prague, September, 1-5, 2009).

meadow restored in 2006 that constituted one of the flagships projects in the area, involved a partially flooded surface of about 12,000 m^2. Usually in these marshes there are not fish, and the rapid proliferation of the species resulted in remarkable increased turbidity, with the ensuing impacts in the native fauna. As a consequence, the restoration measures in that pond had to be restarted from scratch, this entailing the desiccation of the water body (Miquel Campos, pers. com., January, 2011). This is anecdotal information but it is backed by scientific research on the negative impacts of *Cyprinus carpio* in the ecosystems where it is introduced (Barton et al., 2000; Kloskowski, 2011; Koehn, 2010). It is worth noticing that this species, possibly present in Catalonia since the 18th Century (Ordeix et al., 2010), is among the most widespread fish species in the region and according to last available data from the ACA's monitoring routines (Sostoa et al., 2010) is the one with the highest estimate of total fish biomass in Catalonia. Its eradication is out of the question.

From the point of view of water quality, the presence of alien fish species is in fact considered as a pressure on the good ecological status. However, there are few initiatives to specifically control the populations of alien fish in Catalonia. The LIFE + project in the Banyoles Lake mentioned above encompasses activities of alien control through selective fishing. So far, more than 90,000 fish individuals, most of them *Micropterus salmoides* and *Lepomis gibbosus* have been removed from the lake (Pou-Rovira et al., 2013). In October 2009, a pilot test of alien species fishing in the last section of the Ebro river resulted in about 500 catches of alien fish, being *Silurus glanis* (30 percent), *Rutilus rutilus* (24 percent) and *Cyprinus carpio* (14 percent) the most abundant ones (Joel Capdevila, Pers. Comm., 08/07/2010). The project was cancelled after it was made public that the captured fish was to be exported for human consumption in Romania, as this section of the Ebro is highly polluted (see **Section 1.4.1**). The predator fish in the area bio-accumulate mercury, other heavy metals and organo-chlorinated compounds (Balsells, 2009; Benejam et al., 2010).

While presence of the Wels catfish is still recent and it is still possible to detach it from the representation of an 'undisturbed' status of the river, the debate gets more complex when it focuses on so-called naturalized species as *Cyprinus carpio*. Besides the secular present of the species in the regional rivers, together with another AIS (*Oncorhynchus mykiss*, rainbow trout), it is associated with 80 per cent of the angling licenses in Catalan inland waters (Josep Escorihuela, com. pers.). As mentioned above, the Spanish Law of Natural Heritage and Biodiversity (BOE, 2007) foresaw forbidding any use of alien species in sports angling. The difficulties for implementing this measure were such that the regional environmental authorities proposed to the Catalan Parliament the legal 'naturalization' of the carp, creating an ad hoc category thought for this species in the Draft Law of Sustainable Fishing (BOPC, 2008).

A similar debate is related to the so-called 'translocated' native fish species deliberately moved between basins of the same country. They are native to some basins and alien in some others, but from the management point of view this distinction is not made. For instance, *Barbus graellsii* or *Luciobarbus graellsii*, 'Barb de Graells', endemic to the Ebro has been translocated to the IBC and there generates hybridisation issues with the vulnerable *Barbus meridionalis*, 'Barb de muntanya' (Ordeix et al., 2010). However, until 2013 the annual fishing programmes did not recognise it as an alien, imposing the catch-and-release obligation everywhere in the Catalan territory (DOGC, 2013). The situation, though, changed in 2014, when the catch-and-release obligation was restricted to the Ebro basin (DOGC, 2014).

Another practical problem of alien fish management is related to fish restocking in rivers. There are differentiated genetic lineages in wild population of locally valued *Salmo trutta*, brown trout (Cortey et al., 2004). The populations from the Mediterranean (and Adriatic) lineages, considered autochthonous in

the Catalan rivers, have been strongly pressured by overfishing and changes in habitat and they are now considered a vulnerable species (Fernández Cebrián, 2011). Restocking the species has been a response to the strong demand for fishing in the areas where it is distributed. However, the *Salmo trutta* from the Mediterranean lineage is difficult to breed in captivity, in comparison with the more resilient *Salmo trutta* from the Atlantic lineage. For this reason, fish hatcheries usually use the later in their activities (Joel Capdevila, pers. comm., 08/07/2010).

As a result, for decades fish restocking has become a source of introgressive hybridization that reached an average degree of 6 percent along several localities assessed in the Catalan Pyrenees, with peaks up to 20 percent in some sites (Fernández Cebrián, 2011). In 2008, the DGMNB started a pilot programme of breeding *Salmo trutta* of the Mediterranean lineage with promising survival rates (Joel Capdevila, pers. comm., 08/07/2010). However, the annual restocking activities still rely on the introduction of two type of alien trout, the *Salmo trutta* and *Oncorhynchus mykiss*, of which hundreds of thousands individuals are released every year in the areas with most intense fishing pressure, according to the information published weekly by the DGMNB .

In this context, the Fishing Law went through a long process of discussion starting in 2005 (Ambiens, 2014). Initially based on three different scientific assessments requested beforehand, the writing of the successive draft laws and the inclusion of different social and scientific standpoints was controversial. While an issue of dispute was related with the institutional setting for the direct management of the angling areas (with different levels of intervention of the Regional government, the angling federations or the local angling societies themselves), the use of alien species in angling and the type of accepted practices for alien species was certainly a bone of contention.

Currently, the Fishing Law must be recognised as the only general mechanisms for the control of fish invaders in Catalonia, since it introduces the obligation to kill alien fish catches (Art. 18.8). Its final version approved in 2009 (DOGC, 2009), and then modified in 2011 (DOGC, 2011) is nevertheless favourable to the position of the anglers. Globally recognised AIS as *Cyprinus carpio* and *Carassius auratus* are considered as fishing species, same than non-protected native species. This means the general obligation of catch-and-release (Art. 18.6). The presence of other invasive fish such as *Salvelinus fontinalis*, *Oncorhynchus mykiss*, *Micropterus salmoides* and *Esox lucius* is accepted in specific river sections and water bodies with angling interest (Art. 18.7). Restocking with AIS is allowed for certain areas of the angling zoning (Art. 23). After the modification of the Royal Decree related with the deployment of the Spanish Alien Species Catalogue (BOE, 2013), this has meant the authorisation of restocking with *Perca fluviatilis*, *Sander lucioperca* and even *Silurus glanis* in certain areas where the species is already present, besides the other species with angling interest mentioned above (DOGC, 2014).

This wide list of exceptions explains why the scientific community feels that the Regional government is not tackling the issue with the necessary strength. Already in the phase of parliamentary debate, some of the controversial points of the law were contested by scientists specialised in fish fauna.

> "*The law is not sustainable because it does not forbid fish restocking is a clear way.* (…) *Fish planning should be based on the rivers' capacities to sustain angling activities and …* [restocking] *is difficult and expensive.* (…) *Another point that I do not understand is the transport of damaging AIS. The best way to avoid problems is to prevent that the species can be used* (Carles Pla, in Canal Parlament, 2009a)".

> "*The state of the aquatic fauna is deplorable. If we do not act now in twenty years the autonomous fauna communities will be replaced by exotic fauna.* (…) *The problem of the alien species is that it is easy to introduce them but it is difficult and expensive to eliminate them.* (…) [Therefore] *it is important to*

reduce the transport of organisms, even autochthonous or protected species, in order to prevent the transport of other organisms [… and to] *eliminate introduced species according to some ethical procedures* […]. *Restocking with hybrids should be forbidden because it may have negative consequences to native fauna* (Adolf de Sostoa, in Canal Parlament, 2009b).

However, the angling community is not satisfied with the fishing law either. First, as it will be shown with the case of *Silurus glanis* in **Section 1.4**, anglers strongly object the legal obligation to kill alien fish. Second, the anglers claim against being criminalised and blamed for the bad status of the fish communities and argue in favour of their traditional role played in managing the rivers (Trotarríos, 2009). Third, the angling community – which is heterogeneous, from the organisational, ideological and behavioural point of view – includes conservationist positions, as the one sustained by the organisation AEMS-Rius amb vida (www.riosconvida.es). From this perspective, killing catches in areas of genetic conservation (e.g., trout), as it was allowed though the modification of the law in 2011 (DOGC, 2011) undermines conservation objectives and goes against the recreational and economic interest in these areas (Diario de un Pescador, 2011).

It seems clear that the presence and, over all, abundance, of aquatic alien species affect the biological quality of aquatic ecosystems. How is this quality to be assessed? Herein, a discussion about the values of 'nativeness' vs. functionality of the species arises. This functionality can be understood both from the ecological and from the socio-economic point of view. From the socio-economic point of view not all effects of alien fish are unanimously perceived as damaging. Social actors that play a role in the introduction and spread of alien fish also contribute to generate a social defence of their presence in the territory, for the maintenance of sports or recreational activities with economic implications. This point will developed in several sections of the thesis about the case of European catfish.

1.2.3 New menaces, the apple snail in the Ebro Delta

Often, the arrival of a new aquatic invader remains unnoticed by the general public, but that was certainly not the case of the golden apple snail (GAS) in Catalonia. Only some days after its detection in the left hand side of the Ebro Delta on August 1st, 2009 (M.A. López, 19/08/2009), the news was already in the regional television and press by initiative of a popular malacologist involved in science-divulgation (Royo, 2009; Telenotícies TV3, 2009). The species was initially identified as *Pomacea canaliculata* (López Soriano et al., 2009), and later on – after a deeper understanding of the genus *Pomacea* – as *Pomacea insularum* with observed densities up to 1 kg m^{-1} and abundant egg masses in the colonised area (López et al., 2010).

Fig. 7. Egg masses and adult individuals of apple snail in the Ebro Delta (24/0/2009)

Picture: B. Rodríguez-Labajos

The species was not found in the river but in agricultural fields and irrigation canals of an area of intensive rice production. The first assessment of distribution detected a gradient of density from the most likely pathway of introduction, an ornamental fish farm involved in imports, exports and breeding of aquatic

species, basically exotic fish (See **Fig. 8**). According to the website of the company – www.promotora-bama.com, not operative anymore – their 7000 m^2-facilities in the Ebro where the largest one of their kind in the Spanish State. A visit to the facilities and an interview with the manager on August 24th, 2009, confirmed that the on-site wastewater management system plant had the best available technologies at that time, with permit granted by the watershed authority (an administrative procedure in which both CHE and ACA participated). If *P. insularum* was released to the Ebre from the wastewaters from that fish farm, as argued by the rice farmers (Ibeas, 2012) and also in the courts by the Catalan government (Pérez Pons, 2012), either there v
or a failure in the techno
liability, the case is clear
aquaculture facilities', as
concerning use of alien an

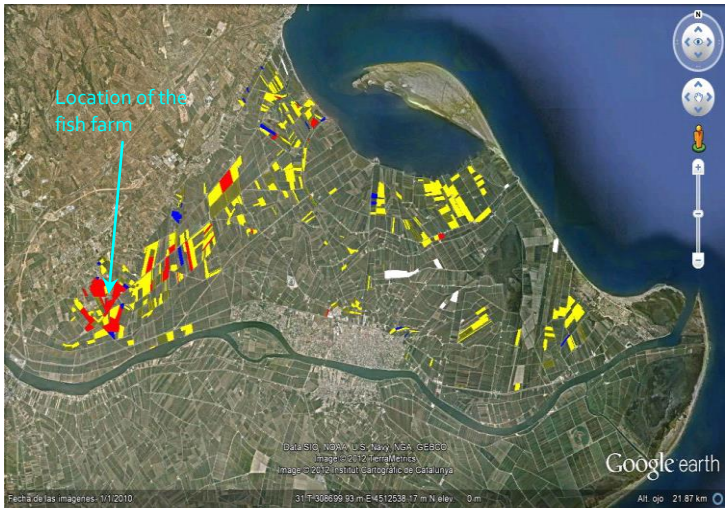
State of the apple snail inva

Note: Colours ir
red (high), orang
blue (newly det

Source: DAAM, 2012; locat

Informe Cargol Poma

ACTUALITZACIÓ INVENTARIS CAMPS ENVAITS



Blau: noves trobades; Blanc: sense caragol (eradicat);
Densitats (situació a desembre de 2011):
Roig: densitat alta
Taronja: densitat mitja
Groc: densitat baix

The invasion of GAS in E
2012 (Europa Press, 2013;
1,600 ha (DAAM, 2014). I
plants during their early st
production losses up to 7
measures started soon aft
desiccation of the rice fiel

Besides being expensive in terms of control and of opportunity costs, some of the measures, such as the desiccation, required exceptional permits from the UE, as this region has been given agri-environmental supports since 2005 for managing the rice fields as wetlands included in the RAMSAR Convention. This agri-environment support would be stopped if the fields are not flooded with river water (European Parliament, 2014b). In fact, many of the measures taken, desiccation in particular, have negative effects on non-target organisms, like birds, and in the natural wetland environment, which creates a conservation trade-off (Ibeas, 2013). Another side of this trade-off is the discontent among bird hunters who complain about the decreasing bird populations (Royo, 2011).

Moreover, the invasion has not been controlled yet and currently efforts are done to prevent the spread to the river, where the earliest colonisation outbreak was seemingly controlled, and to the right hand side of the Delta (DAAM, 2013). The control costs have been basically supported by the Agriculture Department that would have expended at least EUR 1 m (Europa Press, 2013). The European Commission

has provided supporting funds of EUR 2.64 m for control actions against the species during the period 2010-2013 (European Parliament, 2014b). As a consequence of the invasion in the Ebro, a ban on imports of all species from the genus *Pomacea* into the EU was imposed, based on the scientific opinion of the European Food Safety Authority (EFSA) (OJEU, 2012).

1.2.4 As a result, raising social awareness

For many years or indeed centuries, the succession of uninvited arrivals of damaging aquatic invaders to the Catalan territory did not generate a broad social alarm. However, this may have changed in the last decade.

In order to trace the public attention to the issue of IAS, the chronographic use of the terms 'invasive species' (in *plural* in the Spanish original), 'zebra mussel', 'Wels catfish' and 'apple snail' in a well-known newspaper are used as indicators (**Fig. 9**). These terms represent the examples provided above, together with cases that will be explained in detail in **Section 1.4**. The plural use of 'invasive species' (*especies invasoras*) is purposely used to represent generic concern for IAS, rather than for a particular species.

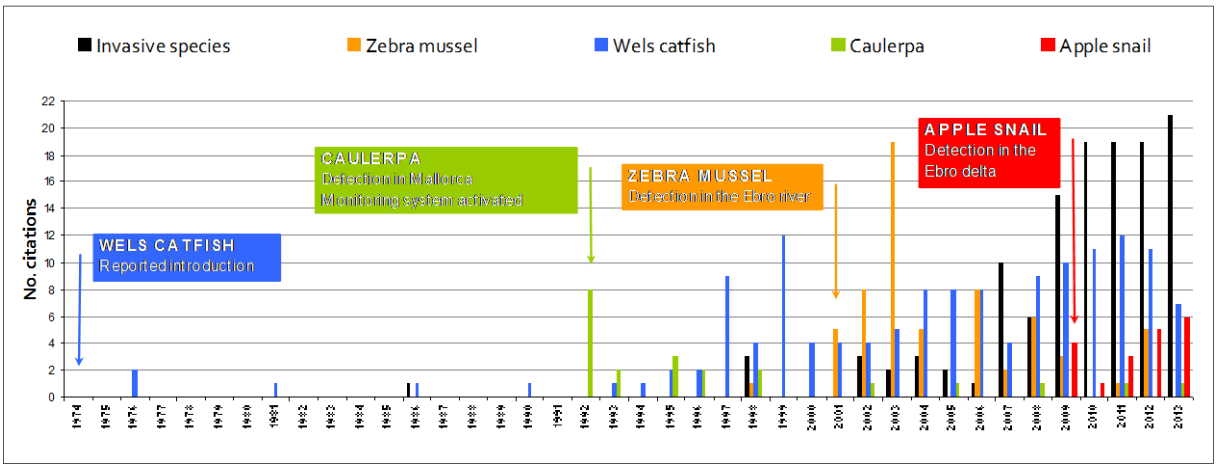


Fig. 9 Use of AIS terms in newspaper articles (1974-2013)

Source: Own elaboration based on the number of citations in the hemerographic services of the newspaper 'La Vanguardia'" (www.lavanguardia.com, consulted on the 10/04/2014). Only relevant entries using the exact terms have been included. La Vanguardia is a newspaper edited in Barcelona, with a daily circulation of above 230,000 copies and ca daily 800,000 readers. Among the paid-for newspapers, it is usually the most read in Catalonia and the third most read in Spain.

The period of analysis in **Fig. 9** starts in 1974, the year of reported introduction of *S. glanis*, European catfish. After two initial decades of disregard for the matter, a trend to a greater public attention is noticeable only after the early 1990s. However, the regular use of the generic term 'invasive species' does not start until one decade later. What can explain this pattern?

Looking at the news contents, the first appearance of European catfish in the newspaper takes place after two years of its reported introduction, in the classified ads to sell equipment for the species angling. Significantly enough, the first use of the term 'invasive species' ever in this newspaper appears in 1996, more than one decade later. Wels catfish is commonly mentioned together with other exotic fish, but the idea of invasiveness still does not take off in the media. Despite the alarm created by the possible arrival of caulerpa in the Catalan coast 1992, with the subsequent implementation of a monitoring system which

results are reported regularly after that date, a broader discussion on bioinvasions seems to be absent in the media.

It is not until the news of the detection of the zebra mussel in the Ebro River when the term 'invasive species' is used recurrently. In fact, after 2009, news about the general issue are more frequent than the information about the particular cases, indicating a greater concern for bioinvasions than a reaction to a specific taxon.

We conclude that the public attention to IAS may have passed from the interest for specific cases towards awareness of the general issue. The cases shown above are examples of charismatic species whose *ad hoc* management started often in response to specific threats. While managers had to learn to deal with unexpected matters, they have progressively developed principles for a more integrated approach in the management of aquatic bioinvasions. In this context it is pertinent to refer to the implications for IAS management of the Water Framework Directive.

1.3 IAS and the Water Framework Directive in the case of Catalonia

After the Water Framework Directive (WFD, 2000/60/EC) (OJEC, 2000), the main water management guideline in Europe, water is seen not only as a resource but also as the element that allows the ecosystems to exist. As such this regulation has become a main driver of ecological restoration of the aquatic ecosystems of the countries where it has been implemented.

The WFD introduced specific objectives to preserve and, where necessary, to improve the ecological status of EU surface waters. This is measured though the assessment of the biological, physico-chemical, and hydro-morphological quality of the water bodies. Each one of these elements is assessed through nationally appropriate procedures. For instance, several assessment protocols were developed for different types of water bodies in the Catalan water district (ACA, 2006a, 2006b, 2006c, 2006d, 2006e). In particular, the BIORI protocol (ACA, 2006a), devoted to the assessment of biological quality of rivers, describes the biological elements (i.e. aquatic flora, invertebrates and fish) and parameters to be taken into account for the quality assessment. Fish are assessed through an index of biotic integrity (Sostoa et al., 2003) that, the same than other elements in the assessment, is subject to a periodic methodological update (Sostoa et al., 2010) and it has contributed to an international effort to intercalibrate the different national protocols.

Although AS are not explicitly mentioned in the WFD itself, its normative definitions (in its Annex V.1.2) point at the need of taking bioinvasions into consideration. In particular, the biological quality elements for assessing ecological status are required to move towards a situation where "*species composition and abundance correspond totally or nearly totally to undisturbed conditions*". Ensuing WFD guidance documents were more precise in this respect, recognizing AS as a pressure with potential impact (EC, 2003b: 31), as possible indicators to monitor human induced changes within a water body (EC, 2003a: 80) and again as a biological pressure that can only be compatible with high ecological status if there is a very minor (or no) impairment of native biota due to the introduction of AS (EC, 2003c: 45).

In face of this, the issue of AIS has been taken into account in the implementation of the WFD in the Catalan water bodies through four main pursuits.

1. Recognition of AIS as a pressure on the state of aquatic ecosystems. A selected group of AIS was considered in the analysis as pressuring to water quality in rivers within the stage of the 'pressures-impact' analysis of the WFD implementation. The first time that this analysis was undertaken, in 2003,

the knowledge on the abundance and distribution of AS in aquatic ecosystems was rather scattered and only some high impact alien species (e.g. *Procambarus clarkii, Trachemys scripta elegans,* and *Mustela viso*) and hotspots of alien fish an flora were registered.[5] More recently, the update of the analysis has considered the information achieved through the Exo-Aqua information system, pondered according to the risk level of the species (Carolina Solà, pers. comm.). Considerations on the risk level of the species and how it has been determined for the case of Catalonia will be explained in detail in **Section 4.1**.

2. Use of IAS in the public participatory process about water management planning. IAS were accepted as one of the discussion elements along the consultation measures for the preparation and approval of the Catalan River Basin District Management Plan, in compliance with the provisions of Article 14 of the WFD. In fact, from the review of the minutes of the workshops made available online by the watershed authority (ACA, 2011)[6], it can be inferred that the issue of AIS spontaneously emerged in all the 16 sub-regions in which the participatory process for the consultation was organised between 2006 and 2010. Summarising these minutes, the scope of citizens' concerns and proposed solutions is presented in **Table 5**.

Table 5

AIS-related items mentioned during the participatory process of the WFD in Catalonia

Source: Own elaboration based on ACA, 2011

Detected problems	Identified solutions
Changes in the ecosystems are noticeable	Research and monitoring of exotic (invasive) species and native species
Angling interests are pushing fish restocking with exotic species	Enhancement of riverbank restoration: need to review the restoration criteria for including native diversity
Abandonment of pet species	To prevent the spread of exotic species both in rivers and marine areas by:
Alien plant species, often used as ornamental, are dominating the river banks	- promoting awareness - avoiding illegal releases - restoring hydrological natural processes (e.g. floods and droughts) - regulating exotic species trade
Few studies about the impact of alien species	To initiate IS eradication campaigns depending on the extent and invasiveness of the species
Lack of intervention: Insufficient surveillance and ineffective control measures	To assess and communicate the impact of invasive species. In this way, it is expected to improve:
Lack (or lack of knowledge) of regulation	- The environmental behaviour of the citizenship - Gardening practices in public areas - Codes of conduct in the gardening business
Lack of information / education	To evaluate the control measures

Besides unveiling a widespread awareness about biological invasions, the precision of both the detected problems and the proposed solutions show recognition of bioinvasions as a problem for water management, the ascription of responsibilities and the needed interventions to redress the situation.

3. Creation of either adapted or *ad hoc* programmes of measures. As an evidence of the need for an improved monitoring of alien species, the *monitoring programme* of the water authority was adapted to achieve more detailed information about the distribution and abundance of AS *taxa*, in particular about the record of macroinvertebrates and riverbank plant species. It is worth mentioning that the existing protocols for the monitoring of macrophytes, diatoms and fish already assured a high level of detail in

[5] Infomation available through the Map Server of the Water Framework Directive by the Catalan Water Agency at http://acamap.gencat.cat/impress/egv.php?lang=ca.

[6] The narrative about the participatory process is also enriched by talks between 2006-20011 with Muntsa Niso (ACA), Jaume Delclòs (ACA), Xavier Fusté (ACA), and Annelis Broekman (Xarxa per una Nova Cultura de l'Aigua, XNCA) and through my participation in the consultation process in Terres de l'Ebre, in the thematic Group 'Hydro-morphological and biological quality' (Horta de Sant Joan, 09/06/2009).

this respect (Carolina Solà, Evelyn García, pers. comm.). Additionally, the monitoring grid for the zebra mussel – which started as an emergency measure from 2006 – has been included as a part of the official monitoring programme.

Beyond that, three programmes of measures linked to the River Basin District Management Plan (2009-2015) had a particular focus on AIS. Thus the *coastal improvement programme* included measures for eradication of alien species in two coastal areas, and the *riverbank restoration programme* included some actions tending to remove plant AIS from the riverbanks and to underpin biological resistance through native vegetation. Finally, a new *programme of measures for prevention, eradication and control of aquatic IS* was introduced for the first time in the context of the river management planning in the Iberian watersheds.

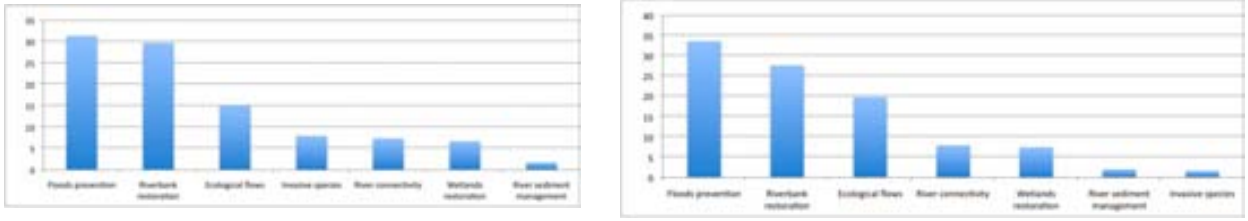
The basic purpose of the program is to contribute to the good ecological state of the aquatic ecosystems by slowing down the spread of AIS present in the territory, preventing their introduction in high risk /strategic areas, protecting water management infrastructures, and organising actions for prevention, early detection and rapid response, eradication and control of and adaptation to AIS in the aquatic ecosystems of Catalonia. The programme has an emphasis on some high risk species like zebra mussel, common reed and some marine species (such as *Caulerpa racemosa*). The actions were to be developed in coordination with other programmes of measures, such as the already mentioned riverbank restoration programme and the programme of improvement of coastal areas, and with other public organisations, in particular with the Natural Environment department of the Regional Ministry of the Environment, who would incur part of the investment costs (ACA, 2010).

The overall Catalan River Basin District Management Plan and the corresponding programmes of measures were approved by the Generalitat (the Catalan government) by the end of 2010 (DOGC, 2010a, 2010b). Thus, it became the first plan approved in the Spanish State within the water planning calendar of the WFD and the only one within the timeline requested by the European Commission.

The importance of this first appearance of the IAS topic within the river management planning is undeniable. Still, the minor allocation of funding to this programme indicates a prioritisation of other measures in the improvement of ecological quality of the water bodies. According to the original financial planning, the total investment for the full programme of measures was EUR 59.2 M during the period 2006-2015, of which around 12% corresponded to costs to be incurred by the watershed authority, remaining the rest for other public organisations (ACA, 2010b: 78). As shown in **Fig. 10**, this makes this programme the smallest of the programmes for the improvement of hydro-morphological and biological quality as far as the water authority is concerned.

Fig. 10 Distribution of investments within the programmes of measures for hydro-morphological and biological investment, 2006-2015 (%)

a) Cost for all institutions **b) Cost for ACA**



Source: Own elaboration based on data from Annex I of the Programme of Measures of the Catalan River Basin District Management Plan

Moreover, the budget of this programme was impaired by the overall cuts in public expenditure after 2009. The main activities funded were those that had already taken place or started during the period when the water planning was approved. Among those actions, it is worth mentioning the Information System about Alien Species in Aquatic Ecosystems (SI-ExoAqua), together with the assessment of species invasiveness through standardised risks assessments (Andreu et al., 2011), which currently makes Catalonia still one of the regions with the best characterisation of aquatic invaders and risk in Europe (see **Section 4.1**).

This was greatly due to the maintenance of networks of stable collaboration between the watershed authority and diverse research centres, often formalised through *memoranda* of understanding. Some examples are the agreements between ACA and CIEB (1992-2012), ACA and ICTA/UAB (2006-2010), and ACA and CREAF (2009-2011). Mutual respect and understanding of the diverging objectives of science and policy making were key aspects for the collaboration activities during these years.

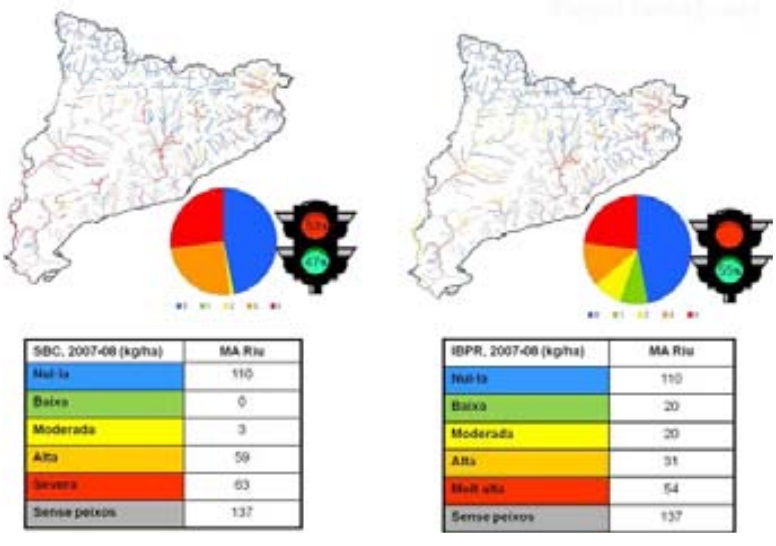
4. Discussion about the consideration of AIS in the determination of the state of the aquatic ecosystems. As in the Catalan River Basin District, the recognition of the AS pressure has lead to authorities from several Member States to develop *ad hoc* programmes of measures. However, still in the context of the WFD, AS are a component of a biological element as well as a biological pressure so their incorporation in the assessment of the ecological status of the water bodies is challenging (Cardoso and Free, 2008). An enquiry on how EU Member States deal with AS in their national status assessments unveiled a wide range of practices (Vandekerkhove and Cardoso, 2010; Vandekerkhove et al., 2013). Most Member States do not take AS explicitly into account in their biological quality protocols, but almost all supported using a biopollution index to enhance a targeted management of this pressure.

The use of the term biopollution to discuss the issue of AS is relatively recent and it has been basically applied to the aquatic environments (Boudouresque and Verlaque, 2002; Elliott, 2003). It conveys the idea that AS disrupt the ecosystem's health and thus impair the ecological quality of the environment (Olenin et al., 2011, 2010). The effects of biopollution may encompass social and economic costs. The most well-known methodologies to assess biopollution are the Integrated Biopollution Risk Index (IBPR) (Panov et al., 2007, 2009) and Biopollution Level Index (BPL) (Olenin et al., 2007). Another related term – also useful for guiding the management response to AS - is biological contamination or biocontamination, that avoids any reference to potential impacts of the species and therefore is not considered equivalent to biopollution. Biocontamination can be estimated through the Site-specific Biological Contamination (SBC) index (Arbačiauskas et al., 2008).

Fig. 11

Estimates of the SBC and IBPR indices for rivers in Catalonia

Source: Ordeix et al., 2010, quotes 'Beatriz Rodriguez-Labajos (pers. comm.)'



In 2009 the watershed authority took part in the meetings in support of the WFD Ecological Status Working Group (ECOSTAT), by inviting the author of this dissertation as a national expert for the case of inland waters. The interim results of biocontamination and biopollution (BC&BP) indices, and their comparison with the indicators for the assessment of biological quality (presented in **Section 4.2**) were used in that discussion and afterwards reported as a personal communication in the Catalan handbook on fish in inland waters (Ordeix et al., 2010). The results (**Fig. 11**) indicated that half of the assessed water bodies in Catalonia have an unfavourable status due to the presence, relative abundance and potential impact of alien fish.

This section has provided an overview of the aquatic bioinvasions in Catalonia. This has been done by offering data about the information available and the management context where this information is used. The management approach has progressively moved from the response to specific cases (charismatic invaders) to a more integrated approach linked to policies of water ecosystem improvement. This has happened in parallel to the growth of social awareness about the issue of bioinvasions as a relevant socio-environmental problem. In the next sections, the specific *problématiques* of two study areas in Catalonia will serve to examine the challenges of IAS management at local scales.

1.4 Downscaling the issue: from the Ebro River to the Internal Basins of Catalonia

The Ebro River drains the largest Iberian watershed, flowing over nine hundred kilometres from the NW to the SE into the Mediterranean Sea. We focus here in the last 150 kilometres of the river. This is one of the hotspots of bioinvasions in Catalonia, with some sections of the river hosting more than one hundred different alien species from the different *taxa* (see

Fig. 3).

Field observations of the stakeholder perceptions since 2004 and the relevant media coverage over the period of study indicate a high diversity of social perceptions about the invaders in the Ebro. Presence of the ecologically and economically damaging zebra mussel (*Dreissena polymorpha*), detected in the lower section of the river in 2001, is supposed to be the consequence of an accidental release. For decades, the same region has been subject to deliberate releases of other aquatic invasive fish such as Wels catfish (*Silurus glanis*) to be used for sports angling.

This section summarises the socio-economic dimensions of the invasions of *Dreissena polymorpha* and *Silurus glanis* in the section of the Ebro River where *D.polymorpha* was initially detected. The case allows tracing the evolution of events regarding the invasion of zebra mussel, as well as the comparison of both bioinvasions in terms of policy responses and social attitudes towards aquatic alien species. Based on this, the situation in another study area that is being under pressure to be colonised by the zebra mussel in the Internal Basis of Catalonia is also described.

1.4.1 The low section of the Ebro River

This study area covers the low course of the Ebro River, along the regions of Aragon and Catalonia, comprising three successive reservoirs (Mequinensa, Riba-roja, and Flix) with a joint capacity of 1.754 hm^3) (**Table 6**). The reservoirs were built in the 1960s as hydroelectric power plants, dramatically changing the livelihood of the residents of the adjacent villages. By 1985, the Ascó nuclear plants also started their operations some kilometres downstream (**Table 7**).

Table 6 Reservoirs in the Ebro study area

Source: ACA, 2014; MAGRAMA, 2014

Reservoir	Surface (ha)	Capacity (hm^3)
Mequinenza	7.720	1.533
Riba-Roja	2.152	210
Flix	320	11

Table 7 Power plants in the Ebro study area

Source: CNE, 2000; Foro Nuclear, 2011

Plants	Ownership	Power (MW)	Year of constr.
Ascó I nuclear power plant	ENDESA	1 033	1983
Ascó II nuclear power plant	ENDESA (85%), Iberdrola (15%)	1 027	1985
Mequinenza hydroelectric power plant (4 product. units, p.u.)	ENDESA (ENHER)	324.0	1964
Riba-roja hydroelectric power plant (4 p.u.)	ENDESA (ENHER)	262.8	1967,1969
Flix hydroelectric power plant (4 p.u.)	ENDESA (FECSA-ENDESA)	42.52	1948

Close to Ascó in Flix, highly polluted loads from the chemical factory, Erkimia, were regularly dumped into the reservoir since the early years of the 20th century (Grimalt et al., 2003). The 'discovery' of about 200,000-360,000 t of accumulated waste, became an environmental scandal of big proportions, as the last 90 km of the river are polluted with organochlorinated compounds for this reason (Bosch i Suades, 2009). Bioaccumulation of mercury and other trace metals was has been proved across several *taxa*, with likely detrimental effects on condition and reproductive traits of fish fauna (Benejam et al., 2010; Carrasco et al., 2011; Cotín et al., 2012). Nowadays a large decontamination project with a budget of EUR 190 m involving European funding, and a time span of 42 months (AcuaMed, 2012), is slowly being undertaken with the participation of several authorities.

Fig. 12 Decontamination works in the Flix reservoir

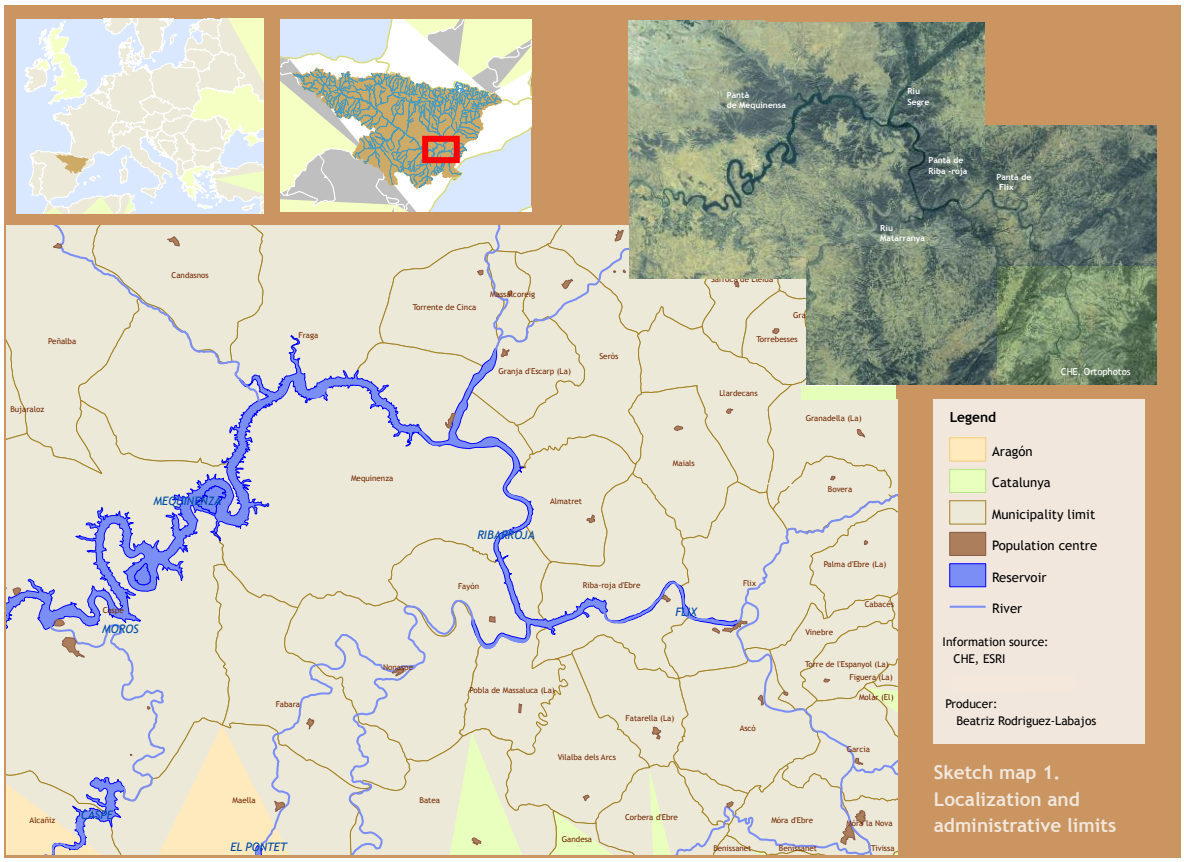
The decontamination process in Flix involves the collection, processing and disposal of 700.000 m^3 of toxic waste as well as the alternative water supply for the municipalities of five *comarques*[7]. A barrier was built to prevent sediment dragging, as observed during flood episodes. Source of picture: Google Earth (01/01/2010), Efe Verde (29/12/2010), Marc Pujols (01/2013, in www.narcisprat.eu).

The Spanish civil war was a landmark of the region's history. Between July and November of 1938, the region was hit by the bloody combats of 'the battle of Ebro' that would define the final victory of the fascist troops in the war. This episode still remains a major reference of the collective memory (CEBE,

[7] *Comarca* (pl. *comarques*) is an administrative territorial unit in Catalonia, above the municipal and below the provincial levels. As there is not an accurate translation of this term, the original Catalan has been used in several sections of the text.

2014) and supports the belief that the area is bound to remain as a peripheral border site, both in Aragon and Catalonia, excluded from the dynamics of their respective administrative centres.

Fig. 13 Sketch map with uses of water in the Ebro study area



However, the defence of cultural elements – such as a specific dialect of the Catalan language used locally in two administrative regions – defines the idea a territory, *La Franja*, with common livelihood concerns: "*I feel my worries closer to people from Mequinenza* [a town in Aragon] *than to people of Tortosa* [a downstream city in Catalonia] (Joan Ignaci Balazote, pers.com. 22/09/05)". This helps to explain that the region has been effective to mobilise social resources against unwanted developments.

Thus the intense public protests against the projects to transfer water to other Iberian river basins contributed to paralyse the uptake of 1,050 Hm^3 per year foreseen in the National Hydrological Plan of 2001 (BOE, 2004, 2001b; Ihan, 2009). In 2008, groups opposing massive wind farming projects in the nearby Terra Alta *comarca* successfully brought their local concerns to the national debate including the organisation of a local referendum in Horta de Sant Joan, claiming lack of opportunities for deliberation about such development (Zografos and Martínez-Alier, 2009).

Despite the polluted water and the changes in the river morphology, the Ebro is still the habitat for remarkable aquatic species, including the last living population of the pearl mussel (*Margaritifera auricularia*) or the native freshwater blenny (*Salaria fluviatilis*), both listed in the Spanish Catalogue of Endangered Species (BOE, 2011b; MAGRAMA, 2014). Natural habitats include Mediterranean bushes and some woods of white pine (*Pinus halepensis*). Along the riverbank, other plant communities such as

reedbeds and poplar forests give shelter to a remarkable number of breeding and migratory birds. For this reason, some areas are already protected and some others are proposed as Natura 2000 sites.

Fig. 14 Sketch map with uses of water in the Ebro study area

Fig. 15 Sketch map with uses of water in the Ebro study area

As shown in **Table 8** the region is sparsely populated, with lower densities than the Catalan and even the Spanish average (around 93 inhab./km^2 in 2011 according the Spanish National Statistics Institute, INE). Occupation rates are lower than the respective provincial figures due to the aging population. From the point of view of the economic activities, chemical and power production plants have an influence for biasing the occupation rates to the secondary sector. In this sense, these municipalities differ from the neighbouring territorial context, where the importance of the agriculture is higher. There, the main economic activities are agriculture (fruit trees in the irrigated area; olive and almond trees and vineyards in the dry areas), pig and poultry farming. The case of La Pobla de Massaluca is an example of this rural context.

Table 8 Population indicators, 2011

Note: 1 Growth between 2001-2011 in percentage (own calculation; 2 Population of 65 or more years old over population between 0 and 14 years old (own calculation). Source: INE, Population Census 2011 (www.ine.es)

Municipality	Total population		Population density (Inhab/km^2)	Aging index [2] (%)	Activity rate		Sectoral occupation (%)		
	Inhab.	Δ (%) [1]			%	Δ (%) [1]	Agriculture	Industry & building	Services
Mequinenza	2425	- 2,5	8,06	191	- 24,3	8,3	8,3	39,5	52,2
Fayón	370	- 6,6	6,04	500	1,7	14,3	14,3	39,3	46,4
La Pobla de Massaluca	365	- 15,1	8,73	207	- 5,3	37,9	37,9	17,2	41,4
Riba-roja d'Ebre	1270	- 3,1	13,28	189	- 17,8	1,1	1,1	43,8	56,2
Flix	3805	- 3,7	34,22	417	- 15,1	2,4	2,4	39,7	57,8
Ascó	1645	1,7	22,40	338	-6,6	15,7	15,7	42,5	41,0

The importance of tourist activities in the area, mostly related to sport angling, has been growing since late 1970s. Central and North European anglers arrive in the area attracted by the abundance of big predator fish. In fact, there is a long list of alien fish deliberately introduced for angling purposes either as game (such as black bass, Pike-perch) or as a bait (such as bleak). Based on the data of fish monitoring undertaken by the Catalan Water Agency (IBICAT), ca 80 percent of estimated fish biomass in Ebro river from the last section of the Cinca to the Ebro near Amposta, is related with alien species (see **Table 7**).

Table 9

Introduced fish species in the Ebro study area

Source: ExoAqua, Barroso (2002) and FishBase (**www.fishbase.org**)

Scientific name	Common name	Native to
Alburnus alburnus	Bleak	Western, Central and Eastern Europe, UK and Scandinavia
Ameiurus melas	Catfish	North America
Carassius auratus	Goldfish	Asia (Central Asia, China, Japan)
Cyprinus carpio	Common carp	Asia
Gambusia holbrooki	Mosquito fish	America (Southern United States and Mexico)
Lepomis gibbosus	Pumpkinseed	America (United States)
Micropterus salmoides	Black bass	North America (United States)
Pseudorasbora parva	Topmouth gudgeon	Asia
Rutilus rutilus	Roach	Central Europe and Eastern Europe, Asia
Sander lucioperca	Pike-perch	Central and Eastern Europe (Rhine and Danube Rivers)
Scardinius erythrophthalmus	Common rudd	Europe and middle Asia
Silurus glanis	Wels catfish	Central and Eastern Europe (Danube River)

Three of these species (*Cyprinus carpio*, *Micropterus salmonides* and *Gambusia affines*, genetically close to

Gambusia holbrooki) appear on the list of the worst 100 invaders of the Global Invasive Species Database (www.issg.org/database). However, as explained next, the economic use of most of these fish makes the implementation of control measures controversial.

1.4.2 Arrival of *Silurus glanis* and *Dreissena polymorpha* into the Ebro

Silurus glanis, in many respects, is a very good example of the contradictory social perceptions about invasive fish species. The release of Wels catfish in the mid 1970s was deliberate. A German biologist and angler, Roland Lorkowsky, declared himself as the introducer of 32 juvenile fish to the Ebro initially originating from the Danube River in 1974. He stated that the introduction of Wels catfish to the Ebro was justified by an imminent 'ecological disequilibrium' (Caza y pesca, 07/1988).

It is likely that further introductions of this species took place during the next years in both Mequinensa and Riba-roja reservoirs. Towards the beginning of the 1980s, the emergence of Wels catfish was regarded with concern by local fishing associations that considered the fish a major menace for local species' survival in the long run (Cañasport, 1984; Correo Catalán, 24/11/1984; Ebre Informes, 28/11/1984; Diario Español 10/10/1985).

The arrival of the species was surrounded by perplexity. For instance, local residents argued the possibility that it was a genetic mutation due to the Ascó nuclear power plant. Another example of this confusion was the initial reluctance of the tourists to swim in the area, for fear of being attacked by the fish (Cambio 16, 15/08/1988). In fact, ignorance is an important feature of this invasion process. Initially, the Catalan Government recognized its ignorance regarding the pathway of introduction and behaviour of the species (BEPC, 28/01/1985) and the existing population levels (Diario Español, 18/11/84). Even scientific experts admitted the lack of knowledge of the ecological impact of the species (Emili García-Berthou, pers. comm. 22/06/05).

Nowadays, the species can be found in the reservoirs of Mequinensa and Riba-roja, and it has spread along the Ebro River and its tributaries the Segre and Cinca. Besides this area, scientific records of *S.glanis* indicate the presence of the species in the Cedillo reservoir of the Tagus River (2002), in the reservoirs of Susqueda and Sau, in the Ter River (2003), in La Baells reservoir in the Llobregat River (2006), and in the Alcántara reservoir in the Tagus River (Benejam et al., 2007; Doadrio, 2002; Pérez-Bote and Roso, 2009).

***Box 2. Silurus glanis*, that lovely aquatic monster**

European catfish or Wels catfish (*Silurus glanis*) is a fish of the family Siluridae. Considered as the largest freshwater fish in Europe, it reaches up to 2.5 m in length and more than 100 kg in weight. It is sedentary, occurring in freshwater ecosystem such as deep and turbid rivers or big lakes and dams (Carol Bruguera, 2007).

It is a nocturnal predator and scavenger (Pohlmann et al., 2001). Due to its big dimensions and voracity it might be a risk to autochthonous fishes and other vertebrates (amphibians, small mammals and aquatic birds) (Carol Bruguera, 2007; Doadrio, 2002). European catfish heavily affects the trophic structure of the ecosystems where it is introduced and it can also affect the water quality of reservoirs (Carol and García-Berthou, 2010). For these reasons, the species has been often qualified as a monster by the local press (Cambio 16, 15/08/1988; La Vanguardia, 15/05/2003).

However this fish has commercial and recreational uses. Native to Eastern Europe (Danube, Dnieper and Volga rivers) (Kobayakawa, 1989), it has been introduced in different European countries for angling purposes (Crivelli, 1995; Doğan Bora and Gül, 2003; Elvira, 2001; Galli et al., 2003; Köprücü et al., 2006; Reading et al., 2011; Stern et al., 2006; Syväranta et al., 2010). It also has been identified among the five invasive freshwater species living in the Baltic (Flinkman and Backer, 2003). Since 1985, there are records of introductions to Algeria, Tunisia and China from different European countries (Kobayakawa, 1989).

Catch of *Silurus glanis* in the study area
Source: http://xvella.free.fr

In the Ebro, as well as in other Iberian watersheds, stakeholders involved in to recreational activities exert their influence to maintain and extend presence of alien fish species in spite of the regulations forbidding new translocations. The ecological impacts of *S.glanis* are not yet completely understood but the increasing abundance has occurred parallel to the decrease of the native fish species. Carol et al. (2009) hypothesize about the shifting diet of the *S.glanis*, from the increasingly scarce native and introduced fish to the relatively abundant American red crayfish (*Procambarus clarkii*). This is another introduced species that outcompeted the native crayfish.

The invasion of *Dreissena polymorpha* in the Ebro started more recently. While the exact date of introduction is unknown, in 2001 an environmental group found some specimens of this alien bivalve in the Flix meander. A survey revealed that the colonization was affecting an area of 40 km downriver from the Riba-roja reservoir (Freixe and Jiménez Ruiz, 2002).

The news of the invasion did not provoke concern except among scientific and environmentalist circles. However, in 2002 the massive damage caused to several infrastructures (see **Section 3.3**) raised public attention. The main risk area, the large Mequinensa reservoir, was rapidly colonized by the zebra mussel despite the response from the watershed authority CHE (www.chebro.es) restricting craft traffic. The seriousness of the invasion became public in late 2006. Since then, a series of larvae samplings has revealed new colonized points from the high course of the Ebro and its main tributaries. Adult individuals were found in the Imperial Canal of Aragon, where a population of *Margaritifera auricularia* still survives.

The public alarm led to the monitoring of zebra mussels in other Iberian basins. Both larvae and adults of the species were detected in three reservoirs of the Jucar basin as of 2005. Spread along the Segura River was made public in 2006 when the *Confederación Hidrográfica del Segura* (www.chsegura.es) reportedly found larvae in several points along the whole basin. This recording was not confirmed in subsequent reports. **Fig. 16** shows the official records of *D.polymorpha* provided by the different administrations in charge of monitoring the spread of the species until 2008.

After that date, the species has been found also in other areas. In 2009 it was detected in the Bermejales Reservoir, connected with the Iznájar reservoir, in the Guadalquivir River, between the Andalusian provinces of

***Box 3. Dreissena polymorpha*, the curse of the wandering mussel**

The zebra mussel (*Dreissena polymorpha*) is a bivalve mollusc belonging to the family Dreissenidae. Small in size (less than 5 cm), it occurs in freshwater habitats such as estuaries, rivers, and lakes at temperatures ranging between 12°C and 20°C but it can survive between 0 and 30°C (Olenin et al., 1999).

During the last 200 years, the zebra mussel has spread around Europe (Karatayev et al., 1997). In the mid 1980s, the species reached North America, where it colonized the Great Lakes and extended through the Mississippi River down to the Gulf of Mexico (Minchin et al., 2002).

Its extended distribution is the result of a highly reproductive capability; - a mature female produces one million individuals per year - the larval transport with the water flow along with its ability to survive out of the water for several days (Olenin et al., 1999). The most important pathways for its spread are craft traffic (ballast water, hull fouling) and the creation of invasion corridors such as canals (Carlton, 1996, Kraft et al., 2002, Minchin and Golash, 2002).

Some birds, fish and crayfish predate *D. polymorpha.* Yet the role of natural enemies in suppressing population density is limited due to its high reproductive potential (Molloy et al, 1997).

Impacts are related to its capacity of filtering planktonic organisms from the water and attaching to solid surfaces in very high densities (Johnson and Padilla, 1996). Pipes and other infrastructures can be seriously damaged, causing important economic impacts (Pimentel et al., 2005). It is listed as one of the 100 world's worst invaders by the Global Invasive Species Program (www.issg.org/database/).

Zebra mussel colonizing the Riba-roja reservoir

Córdoba and Granada. Both are well-known recreational areas for angling and navigation. Although both activities were forbidden in Bermejales soon after the detection of the species, the invasion of Iznájar was confirmed in 2012 (Junta de Andalucía, 2012).

In 2007 the presence of larvae in very low density was reported in the Lareo reservoir in the Cantabrian basin flowing to the Bay of Biscay. After repeating the sampling with negative results, the regional government ruled out the invasion (El Correo digital, 13/08/07). In 2008, the detection of larvae in the Ulívarri-Gamboa reservoir, in the Zadorra River (Ebro basin), raised fears that the invasion of the Cantabric basins was imminent, as this is the connecting point of water transfer to the Bilbao metropolitan area, via the Urrúnaga reservoir, also in the Ebro (El Correo digital, 14/11/08). The colonisation of the Urrúnaga reservoir was confirmed in 2011, at the same time than the invasion the reservoir that receives a water transfer from it, the Undúrraga reservoir, in the Arratia River, already in the Cantabrian basin (CHC, 2011). The invasion of the Ulívarri- Gamboa was also confirmed in 2012, same than the Mendikosolo reservoir in the Nervion river basin (URA, 2014).

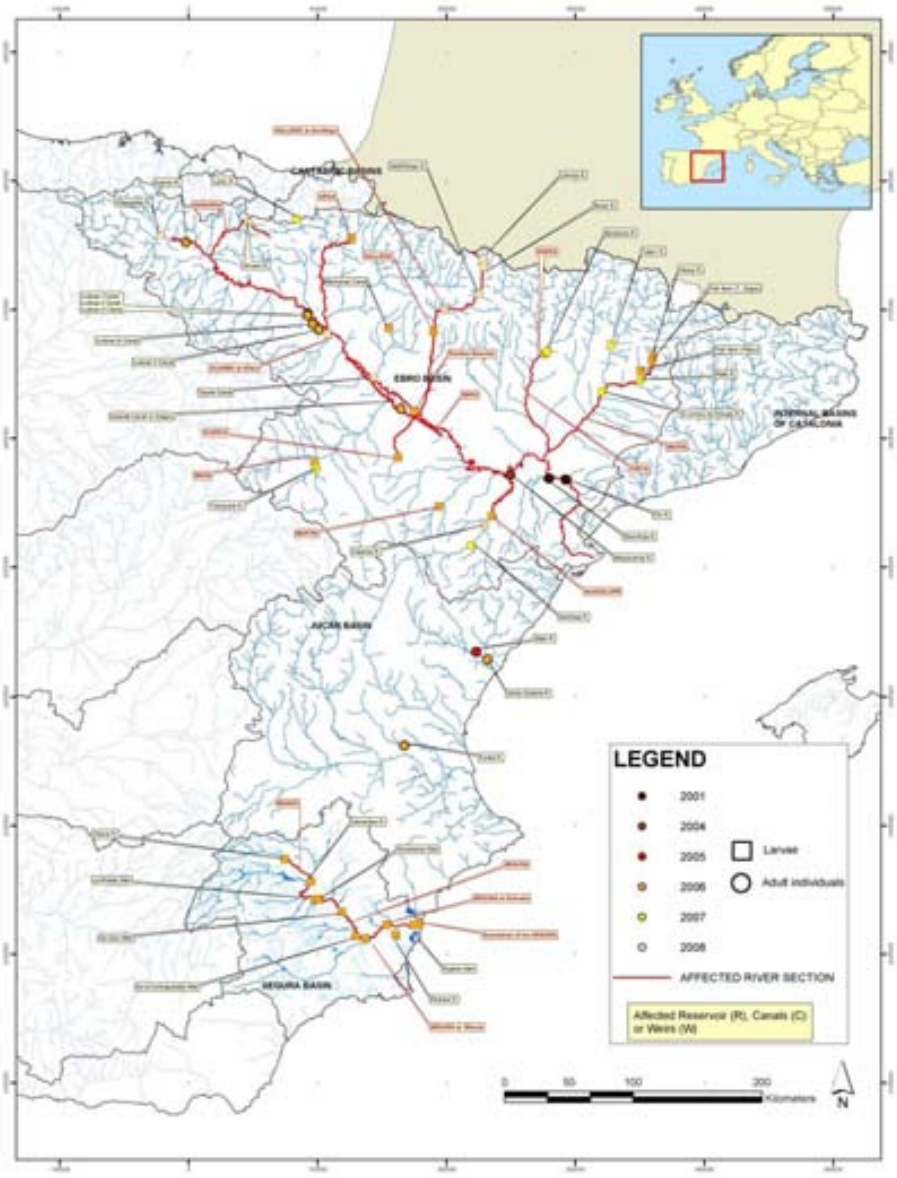
In Catalonia, there is evidence of the spread of *D. polymorpha* to the IBC since the summer of 2011, where adult individuals were found in La Baells reservoir, in the Llobregat River with population peaks in 2012. Also in 2012, larvae were detected in the Gaià reservoir, in Tarragona (ACA, 2014b).

Fig. 16

Records of *D.polymorpha* in the Iberian Watersheds, 2001-2008

Source:

Rodríguez-Labajos et al., 2010

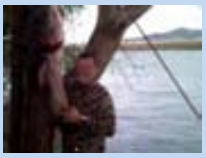


1.4.3 Management of the species

Interviews with scientific experts and local stakeholders reveal the impracticability of the **European catfish** eradication from the technical, economic and social points of view. In **section 1.2.2** a failed attempt at commercial fishing for export was explained. In the regional fishing regulations, *Silurus glanis* is listed as a damaging introduced species that must be controlled in inland waters. As explained in also in **section 1.2.2**, this entails the obligation to kill the catches.

This strategy relies on recreational angling as the main management practice for controlling the invasion. However, the scheme faces divided positions among the actors in charge of its implementation. Such views can be appreciated in several specialized *fora* (www.fcpeic.com, www.facebook.com/FCPEiC; www.federpesca.com). While some anglers admit the advisability of avoiding the spread of the species to other river basins and protect native fauna (www.facebook.com/AEMSriusambvida), practically all of them express categorical opposition to the forced killing of the catches. Bioethical values and/or preservation of the sportive value of the rivers are adduced for defending a 'catch and release' policy rather than the systematic killing of catches. See an example in **Box 4**.

Box 4 ***Anglers' r*****eactions to the killing of AIS catches in the Ebro**



Source: Selected posts, translated from the original Catalan or Spanish, during the period 07-08/04/2014, as response to the post "Siluro de 2,35 m y 122 kg. Vídeo 1:01 de Felipe f.r. el 29/03/2014", in the Facebook account of the FCPEiC (www.facebook.com/FCPEiC), with hyperlink to the original YouTube video

Angler A. It is shocking that the Federation uploads a video with a poor catfish hanging from a tree. This is the image that we want to give to the world? (…) It is not surprising that many people think that we anglers are animal mistreaters. Shameful!

Angler B. Very sad, even if you want to justify it with the excuse of a regulation. (…) For me, those who are not willing to flout the [Fishing] Law are torturer fish-killers (…)

Angler C. [The fish] is not autochthonous and it has left us without carps, among other things … [The situation] is ugly, but this is an alien fish that kills our species.

Angler D. Look, Angler C. Besides the barb, which is native to this country, can you tell me another fish in reservoirs that is not [an alien]? The carp? It is native to China. The pike-perch, the bass? What do we do? Do we kill them all? And what do you want to fish if we do that? We all, anglers, like to get a good trophy; this is the angler's ego. But we need to understand that, if we kill the fish, we will not have anything. (…) I refuse! No matter what the Law says.

Angler E. It's one thing that the Law says that invasive species have to be killed. You can agree with it or not, but it is the Law. What the people are complaining about here is the mistreatment and the lack of respect for the fish. If you want to kill it, do it (…). But do not hang it from a tree and make this viral through the internet; it is a sad thing to see. And all right, this is a catfish, but I don't think this kind of anglers have more respect for any other native species. In sum, to see an animal hung from a tree is distressing, whether it is a dog, a trout or a catfish.

The defence of voluntary catch-and-release angling is itself a manifestation of the contradicting views within the angling community. In this respect, Arlinghaus (2007) also reports intrasectoral conflicts dividing the recreational carp-angling community in Germany. The practice is motivated by animal welfare concerns and results in low fishing mortality. At the same time it is strongly criticised for ethical reasons (it tolerates pain and suffering of the fish) and, for some, it perpetuates a view of anglers motivated only by catches of trophy fish and by the experience of enduring fight. In the case of the Iberian rivers, it could be added, it contributes to maintain the stock of alien fish species. According to

Arlinghaus, in Germany this heated debate has brought a decreased acceptance of anglers who practice total voluntary catch-and-release, creating incentives for them to fish abroad.

It is worth reminding that, in Spain, the regional ministries of the environment regulate and sanction angling practices in their territories. In Catalonia, the 'accidental' fishing of the European catfish outside the two authorized areas in the Riba-roja reservoir is tolerated as a controlling measure. While the use of living bait was prohibited in Catalonia, the Government of Aragon exceptionally allowed this practice in the Riba-roja and Mequinesa reservoirs (they are forbidden in the rest of the region) based on the importance of angling for this area's economy. Angling societies and local business at the Catalan shore of the Riba-roja reservoir observed this disparity with certain annoyance.

Nowadays the situation is the opposite. The Aragonese environmental authorities, actively involved in measures for the zebra mussel prevention and control since the detection of the species (see them in www.aragon.es) do not allow the use of living bait (only sardine deadbait is allowed). Then, in Catalonia after 2009, the new fishing law in Catalonia introduced an exception in the use of living bait for water bodies bordering Aragon (such as the Riba-roja reservoir) (DOGC, 2009: Art. 31). This is valid for some angling societies Almatret, Granja d'Escarp i Riba-roja d'Ebre

Other control measures for the Wels catfish take advantage of management routines for canals and reservoirs to kill the European catfish, together with other alien organisms, and to rescue native fish species. That is the case of the annual emptying of the irrigation canals of the Ebro delta since 1990 (El Punt, 25/05/2004) and the occasional emptying of reservoirs, as the Sau reservoir in northern Catalonia in September of 2005 (El Punt, 15/10/2005). In the 2014 campaign, the technical staff in charge of this task in the Ebro delta reported a substantial decrease of total fish biomass. While in 2005 there were about 12 t of fish catches, in 2014 the amount was 1.9 t. This is attributed to the control measures of apple snail, which may have facilitated the escaping of the fish from the irrigation infrastructures (Millan, 2014).

Table 10 Response to *S.glanis* in the Ebro River

Source: Own elaboration

Stage	Measure	Leading organisations	Participants
Prevention	Informative campaigns	ACA, DGMNB	Angling societies, general public
Early detection	No formal monitoring system	-	-
Control	Legal obligation to kill the catches	DGA, DGMNB	Angling societies; enforcement officers (e.g. Rural rangers)
	Wels catfish killing during with infrastructures management	DGMNB, ACA	Government officers (e.g. protected area managers), angling societies,
Adaptation	Use of the species for angling purpose	No formal leading organization	Local business, angling societies
Institutional and scientific support	Inclusion of *S.glanis* as pressure indicator in the pressure-impact assessments	CHE, ACA	Scientific experts, participatory processes of the WFD implementation
	Research	UdG, UB, IRTA	Researchers, local NGO

Eradication of the **zebra mussel** in the Spanish reservoirs and river sections is not regarded as feasible since the most effective control measures (chemical and thermal) are not advisable in natural systems. For this reason, the main objective of the policy initiatives has been to prevent the introduction of such species to new water bodies, through the intervention in the dispersal pathways (boat traffic and angling related-practices such as fish restocking). In addition to the work developed initially by the basin authority, CHE, the regional governments have developed their own programmes; among them the

Aragonese Ministry of the Environment, the Catalan Ministry of the Environment lead by the Catalan Water Agency, and Government of Cantabria. Other regional governments from the different areas invaded by *D. polymorpha* have got involved in the species' control.

Coordinated by the Spanish Committee of Biodiversity, the regional and watershed authorities have applied their experiences to develop a joint Spanish strategy for zebra mussel control that was approved by the Sectoral Conference on the Environment in September 2007 (CSMA, 2007; MMA, 2007). The strategy is a planning effort that foresees common procedures and measures for regulating and managing actions for zebra mussel prevention and control. However, no funding or other resources were given for the implementation of this strategy. Moreover there was a long delay between the moment when the species was initially detected and this common management initiative. In the meantime, different stakeholders have developed different responses according to their specific interest. **Table 11** shows an overview of the main implemented measures.

Table 11 Response to *D.polymorpha* in the Ebro River

Source: Own elaboration

Stage	Measure	Leading organisations	Participants
Prevention (to entry)	Informative campaigns, workshops, travelling exhibitions and training courses	Government of Aragon, CHE, ACA	General public, boat holders, irrigation societies, public surveillance
	Disinfection protocols for canoes (cleaning and drying) and motor boats (hot water)	Government of Aragon, CHE, ACA	Associations of anglers, boat holders, canoeists and water-skiers
	Craft traffic restrictions and inventory of access points in the river banks	CHE, ACA	Rural rangers, marinas
	Temporary ban of angling in affected areas, larvae monitoring in fish repopulations	Catalan Ministry of the Environment	Anglers, fish hatcheries
	Control of fish repopulation	DMHA, ACA	Fish hatcheries managers, angling societies
	Disinfection and safety protocol for forest fire extinguishers	Spanish Ministry of the Environment, Catalan Fire Department	National and regional fire departments
Early detection	Monitoring of larvae and adults	CHE, ACA	Environmental NGO, rural rangers, scientific advisors
	Survey to irrigation societies	ACA	Environmental NGO, irrigation societies
Control	Control of heating water before it enters the cooling system in a nuclear power plant	Ascó nuclear plant	Ascó nuclear plant managers
	Proposal of drastically dropping the water level and flow of the reservoirs	CEPIDE, CHE	Not implemented due to the opposition of angling societies and municipal councils
	Chemical control in closed systems (infrastructures for irrigation and municipal water supply)	CHE, ACA	Municipalities, Irrigation societies, supported by regional government departments
Adaptation	Filtering systems in water transfers; sand filters in infrastructures	Cantabric Hydrological Confederation, ACA	CHC, CHE; infrastructure managers
	Engineering solutions for protecting water uptake systems (filtering)	Agriculture authorities	Municipalities, industries and irrigation communities; infrastructure managers
	Use of antifouling covers	ElNDESA, tourism industry	ENDESA, Boat owners, marina managers
Institutional and scientific support	Creation of a technical advisory board	CHE, ACA	Regional governments, Electric company
	National coordination (design of a Spanish Strategy for Zebra Mussel Control)	Ministry of the Environment	Watershed authorities, regional ministries of the environment
	Creation of scientific and social advisory boards	ACA	Universities and research centres, environmental NGO

Promotion of research projects	Ministry of the Environment, CHE, ACA	Universities and research centres, environmental NGO

Main control measures in closed systems used in Spain have been thermal treatment, applied in the Central Nuclear de Ascó (Asociación Nuclear Ascó –Vandellós, 2003) and chemical treatment with chlorine and hydrogen peroxide, in irrigation and municipal supply infrastructures.

A proposal of drastically lowering the water level of the Riba-roja reservoir to increase zebra mussel mortality and emulating floods to eliminate larvae was not substantiated. After the discovery of the species upriver, this proposal lost any viability. However, the hydrological behaviour of the river during the last years has experienced a combination of considerable drops of the water level (above the 40 percent of the Mequinensa reservoir capacity in the summers of 2005-2007) and sudden river floods (in the spring of 2006-2008 and in the fall of 2006 and 2007) (CHE, 2008). This may have favoured certain control of the populations. Currently, the species is widespread in the lower Ebro, but at densities lower than in 2002.

Water transfers from the colonized areas or from areas at risk entail a main concern for water managers. The water transfer between a still unaffected Ebro reservoir at the headwaters of the basin, and the Besaya river, in the Cantabric basins, was temporarily stopped in 2006 for precautionary reasons (El Diario Montañes, 09/11/2006). Since 2007 a pilot filtering system paid for by the Spanish Ministry of the Environment processes up to 17000 m^3/h of water. According to its managers, the cost of the installation of the infrastructure was around EUR 5 m (Acuanor, 2007). Similar schemes are considered for the reservoirs in the Ter River supplying water to the urban area of Barcelona, trying to mitigate the potential impact of the possible invasion of the internal basins of Catalonia. All these measures are taken with the aim of slowing down the spread of the invasion, although few actors believe that it can be totally stopped.

The Catalan Water Agency (ACA) took over the control of the zebra mussel in Catalonia from the DGMN since 2006 (ACA, 2008b). ACA decided to integrate preliminary results of the author's research (Rodríguez-Labajos, 2006), within its management scheme and also in its contribution to the Spanish Strategy for the Zebra Mussel Control. The aim was to develop prevention and mitigation measures based on shared responsibility and active public participation. In order to prevent the spread of the invasion to non-impaired areas, there was a focus on the dispersal pathways. Control of fish restocking, restrictions to craft traffic and the development of a craft disinfection system, were agreed upon with regional sports associations (anglers, boat holders, water skiers and canoeists) and local stakeholders and a series of co-produced dissemination materials was made available in several languages (ACA, 2012).

Institutional coordination entailed management measures involving several governmental agencies at the regional and national scale. An example of such coordination is the protocol for fish restocking, prepared together with the Fishing service of the DGMNB, and the monitoring of the invasion based on larvae sampling and tracking of the population's distribution and density (ACA, 2014c), as well as protocols for action after the early detection of the species in the IBC (ACA, 2009). A pilot scheme for detection through genetic techniques was also tested.

It is to be noted that the response to the invasion was not accompanied by any restoration measure. As a part of the control to the river, the Catalan Water Agency and the CHE agreed in May, 2008 to promote the riverbank restoration to stop uncontrolled boat access. There has been little progress in this respect.

1.4.4 The situation in the internal basins of Catalonia

This section focuses on an area of Catalonia where the driving forces of the *D.polymorpha* invasion are also operating but, to the best information available at the completion of this thesis, has not been colonised by this species yet. This, together with certain similarities with the original area of invasion in the Ebro, and its strategic relevance for water management planning, has focused the analysis on the Sau-Susqueda-El Pasteral system of reservoirs, in the Ter river basin.

The Sau-Susqueda-El Pasteral system[8]

The Ter River flows through several Catalan *comarques* (Ripollès, Osona, Selva, Gironès and Baix Empordà) until its mouth in the Mediterranean in Estartit. It drains an area of 3,010 km², along 208 km. La mean annual runoff is 840 hm³, with an average discharge at mouth of 25 m³/s. The study area comprises three reservoirs located in the central section of the river that are characterised by the elements shown in **Table 12**. Due to the diverse uses of the water in the reservoirs, described below, an area of influence downriver and even outside the river basin is also considered in the study.

Table 12 Characteristics of the reservoirs in the Ter study area

Sources: (a) ATLL; (b) ICC, 2014; (c) ACA, 2014a ; (d) Junta d'Aigües. Anuari de Dades Hidrològiques. 1987-88 / 1988-89 / 1989-90. Note on uses: H – Hydropower production; I – Irrigation; S – Urban water supply, R – Recreation, N – Motor boat navigation, C – Caanoeing, A – Angling.

Basic data	Sau Reservoir	Susqueda Reservoir	El Pasteral Reservoir
Year of the const. (dam) [a]	1948-1962	1963-1968	1962
Comarca [b]	Osona	La Selva	La Selva
Sourronding municipalities [b]	Les Masies de Roda,Tavèrnoles, Tavertet, Santa Maria de Corcó Vilanova de Sau	Osor, Sant Hilari Sacalm, Susqueda	Amer, La Cellera de Ter
Uses	H, I, S, R (N, C, A)	H, I, S, R (C, A)	H, I, S, R (A)
Characteristics of the dam			
Type [c]	Gravity, concrete	Double-curved arch, concrete	Gravity, concrete
Height (m) [c]	83	135	33
Top length (m) [c]	260	360	150
Characteristics of the reservoir			
Capacity (hm³) [c]	151,3 [c] / 168,5 [d]	233 [c], [d]	2 [c]
Reservoir surface (ha)	572 [c] / 805 [d]	466 [c], [d]	34,6 [c]
Basin surface (Km²) [c]	1522	1775	23
Top water level (m) [d]	426	351	n.a.

The **Sau Reservoir** is located within the municipalities of Tavertet, les Masies de Roda, Roda de Ter, Tavèrnoles and Vilanova de Sau, in the *comarca* of Osona (ICC, 2014). The construction of the dam took

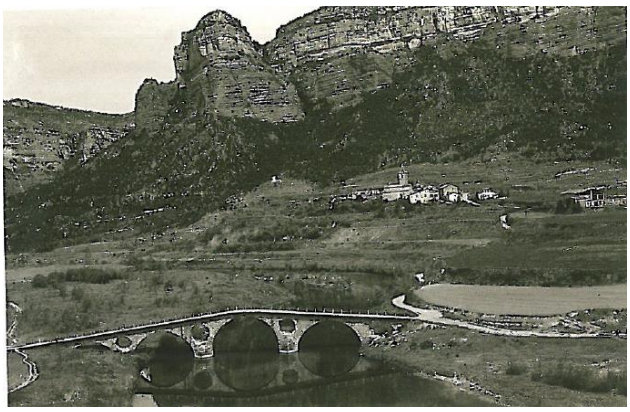
[8] Unless otherwise specified, information source in this section is the Catalan Water Agency. Particular acknowledgement is due to the personnel of the Departments of Aquatic ecosystems monitoring and improvement, Water supply planning, and Regulation infrastructures. With acknowledgement to talks between 2007-20011 on different technicalities in infrastructure planning and operation with: Andreu Manzano, Carlos Barbero, Jesús Martínez, Jordi Rovira, Jordi Molist, Laia Núñez, Mònica Bardina, Sergi Morilla and Xavier Fernández (from the Catalan Water Agency) and with Juan Carlos García and Fernando Valero (from *Aigües del Ter-Llobregat*). Several fieldtrips in the period 2008-2011 were carried out together or with the assistance of some of the people mentioned. This section builds on work done in the context of the Project 'Development of models and technologies for the prevention and control of zebra mussel' (072/SGTB/2007/1.1), coordinated by Dr. Carles Ibáñez.

place between 1949 and 1962. According to the engineer in charge of works, Josep Maria Llançó, the public hearing revealed that the worst affected by the project were '*the industrial entrepreneurs of the low Ter River from Sau to the sea, the farmers that for a long time had been expecting to use this water to irrigate, and the villages that exploited wells for municipal supply and who also wanted to make use of the river*'. He also reports that the manpower for the construction of the dam were from outside the region, generally from Andalusia. The local residents were mostly attached to agricultural activities. '*The locals were pagesos* [farmers] *and had their land*' (Llançó, 2003: 21-24). Later on Llançó became the head of the water supply administration, the *Junta de Aguas de Catalunya*.

Fig. 17

Operative since 1962, the Sau reservoir flooded the village of Sant Romà, including the Romanesque church of the 11th century, whose remains are visible when the level of the reservoir drops substantially

Source: ATLL



The area has a Mediterranean climate with Atlantic influence. The average rainfall is 750 mm, with a decreasing trend during the last years. The stream flow regime shows discharge peaks during May and June, due to the combination of spring storms and snow melt. The reservoir reaches its top level by the end of June and the lowest at the end of September. Data by ACA(2014a) indicate that the capacity of the reservoir is 151.3 hm^3, with a surface of 5.7 Km^2, comprised in a water mirror of 17 km length and 3 km width.

The Euro-Siberian and the Mediterranean areas converge in this region, situation that has created many microclimates and high diversity of plant and animal species. For instance, 173 out of 480 vertebrate species present in Catalonia can be found in the reservoir and surrounding environment. In fact, the regional General Directorate of Natural Environmental and Biodiversity reports the presence of species with economic interest (otter, *Lutra lutra*) and the tail end of the reservoir limits with a Natura 2000 site (ES5110005 Sisstema transversal Català).

As the following pages will describe in detail, the main consumptive use of the stored waters is municipal water supply, for the most part in the Metropolitan Area of Barcelona. There is also water supply for agriculture and the dam is used for power production. The remarkable landscape of the area has fostered the development of recreational activities, among them angling and navigation, currently allowed in the reservoir.

The **Susqueda reservoir** is located within the municipalities of Susqueda, Sant Hilari Sacalm and Osor (the dam is placed in the latter), all them in the *comarca* of La Selva (ICC, 2014). The construction of the dam started in 1963, after local resistance. The operation of the dam, starting in 1968 flooded the village and *masies* (farms) of Susqueda, the municipality that comprises most of the reservoir. The objective of the promoting company, *Hidroeléctrica de Catalunya*, was power production and warranting the water supply of the Barcelona and Girona conurbations. This is the largest reservoir among the three in the study area, with a capacity of 233 hm^3, a dam height of 135 m and a top leght of 360 m (ACA, 2014a).

The reservoir dimension and the fact of it being located in a sismic area made the population fear the possible breaking of the dam, and the ensuing flooding of the towns in the Ter valley until Girona. In fact, a novel by Miquel Fañaràs (1983) recreates this possibility. Several web sites (www.xtec.cat, El punt, 22/04/1983) report an episode of social alarm among the populations of the Ter valley after the radio reading of some passages of the novel in April 1983, as the residents though that the dam had really collapsed.

The local landscape is configured by the Guillerías massif and the Collsacabra mountain range, dominated by oak forests, with remarkable attractive for leisure activities. Besides the water supply and power production, the reservoir has a significant function in terms of water flow regulation.

El Pasteral reservoir is placed in the municipalities of La Cellera de Ter – a neighbourhood of which gives name to the reservoir – and Amer, both in La Selva *comarca* (Institut Cartogràfic de Catalunya (ICC), 2014). According to data by ACA, the reservoir surface is only 35 ha, with a top capacity of 2 hm³. Despite its small size, its relevance for the municipal water supply in Catalonia is crucial. This is the starting point of the aqueduct that brings water to the drinking-water treatment plant (called the *ETAP del Ter*), supplier of the Barcelona conurbation. Downstream from the dam, the bypass El **Pasteral II** is in its turn the intake point for the water supply of the Girona conurbation, a smaller urban area in Catalonia.

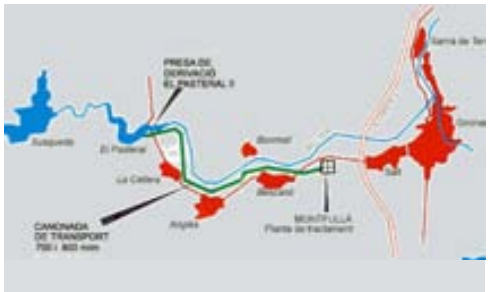
Water uses in the Ter study area, vulnerability to and prevention of the zebra mussel invasion

a. Drinking water supply

The water in this section of the river flows through a system of three successive reservoirs that play a role in a large-scale water stabilisation process. Therefore, the water quality in the intake points is relatively high and the treatment requirements for human consumption are smaller than the water from other areas of Catalonia. This is an important human-mediated ecosystem service that can be disrupted by the possible presence of the zebra mussel. The municipal uses of water involve infrastructures such as pumping stations, canals and water tanks. All these elements are potentially damageable by the species in case of the colonisation of the reservoirs.

Table 13 Urban water supply systems obtaining water from the study area

Source: ATLL (www.atll.cat) and Aigües de Girona, Salt i sarriá de Ter (www.aiguesdegirona.cat)

Companies	Aigües del Ter-Llobregat	Aigües de Girona, Salt i Sarriá de Ter
Intake point	El Pasteral reservoir	CH El Pasteral II bypass
Supplied municipalities	58 municipalities (3.3 M inhab.) (see Annex I); (of which 33 municipalities (0,73 M inhab) depend more than 90% on this system for water supply)	Girona, Salt and Sarrià de Ter. Usptream supply: Bescanó, Sant Julià de Ramis, Vilablareix, Quart and the centre of Costa Brava
Location in the hydraulic network	Gallery of 56 km until the *ETAP del Ter* (Cardedeu); then another gallery of 22.4 km until the Trinitat distribution station	Water channeled until the ETAP de Montfullà, from there two branches towards Salt-Sarrià de Ter and Palau
Sketch map		

The dammed waters from this zone have a central role within the Water Supply Plan of Catalonia (PABCAT for its Catalan acronym). The Barcelona and Girona conurbations obtain upstream water supply from this region, through the (so far) public companies *Aigües del Ter-Llobregat* and *Aigües de Girona, Salt i Sarriá de Ter*, respectively (**Table 13**).

In the first case (**Fig. 19**), the water taken from El Pasteral reservoir is brought 56 km through a tunnel of 2.8 m width and 3.15 m height until the *ETAP del Ter*, located in the municipalities of Cardedeu, La Roca and Llinars del Vallès. In this large drinking-water treatment plant (with a capacity of 8 m^3/s), the water is treated through pre-chlorination, decantation (sedimentation), activated carbon filtering, and chlorination (ATLL, 2004).

Fig. 18

Outline of the water gallery from the Pasteral dam to the ETAP del Ter (Cardedeu) and from there to the Trinitat distribution station (Barcelona)

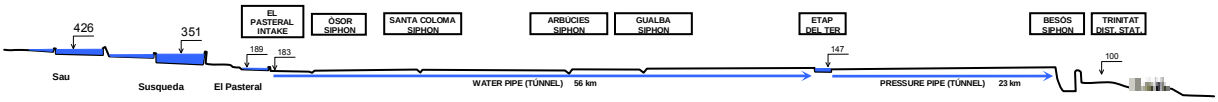
Source: ACA / Own elaboration (with assistance of C.Cardona) based on data from ACA

Once treated, the water is brought 22.4 km to the Trinitat distribution station, in Barcelona. Since the completion of the two-way connexion between the Fontsanta tank (supplied by the *ETAP del Llobregat*) and the Trinitat distribution station (supplied by the *ETAP del Ter*) by the end of 2011, both systems are fully integrated in a single water distribution network (ATLL, 2012). Thus some municipalities of the Metropolitan Area of Barcelona receive water indistinctly from both water basins. Still, according to data from ATLL, the *ETAP del Ter* supplies at least the 58 municipalities listed in the **Annex I**, with a total population of 3.3 million inhabitants, which where the municipalities previously served. According to data provided by ACA, 33 of them (i.e. 0.73 milion people) were totally dependent on the system, obtaining less than 10 percent of their water supply from alternative sources (Laia Nuñez, pers. comm.).

It worth saying that four municipalities (Sant Pere de Vilamajor, Santa Maria de Palau Tordera, Sant Celoni and Breda) extract water directly from the aqueduct before it is treated in the ETAP del Ter. Also the municipality of Santa Coloma de Farners does not take water directly from the aqueduct but, during the last years, an agreement with ATLL has allowed that water is derived from the aqueduct to the Santa Coloma stream, so the water can be taken indirectly from wells along the stream (Jesus Martínez, pers. comm.).

Fig. 19 Water flow through the Ter-Llobregat system

Source: ATLL



By facilitating the identification of major infrastructures along the pathway of the water abstracted from the Ter for drinking supply, the outline shown in **Fig. 19** helps to identity the weakest points in terms of the vulnerability of the infrastructures in the Ter to zebra mussel invasion. They will be described in more

detail in **Chapter 3,** dealing with the impacts of the species. Here some of the main impact categories are shown in

Table 14.

Currently there is a filtering system in the intake of the Pasteral reservoir of 250 µm pore size. This is clearly insufficient to prevent the effects of the invasion, as it is generally recognised that filters with pore sizes larger than 40 µm will not keep the larvae out of pipelines

Table 14 Vulnerable points in the water supply infrastructure to the *D. polymorpha* invasion

Source: Own elaboration. Pictures by B. Rodríguez-Labajos and ATLL

Vulnerable point		Possible damage costs	Possible control costs
Intake towers in the Sau and Susqueda reservoirs		Intake and pumping devices in Sau and Susqueda inoperative or inefficient Losses of hydropower production	Replacement of devises; antifouling covers
Intake in El Pasteral dam for water supply		Silting and clogging of filters and intake devises	Change of the filtering system Pre-chlorination treatments since the intake point
Tunnel of the aqueduct from Pasteral		(Unlikely) clogging of tunnel Damage of water supply intakes along the tunnel	Uncertain
ETAP del Ter		Silting and clogging of purification devises in the water treatment plant	Intensification of pre-chlorination in the arrival point to the treatment plant

b. Irrigation

In the area, the main irrigated lands are located downriver from the Pasteral reservoir (

Table 15). According to Agriculture department, they are fundamentally gravity fed irrigation systems although there are some pressure irrigation systems after the Colomers dam (Manuel Esparch, pers. comm.). This is a facility built in 1974, with the purpose of promoting irrigation in the area. However the reservoir (whose foreseen capacity and surface were 1 hm^3 and 70 ha respectively) was never operative due to the high soil permeability in the area.

Table 15 Main irrigation societies in the low Ter and Daro river basins

Source: ACA – PZBT

Irrigation society	Intake point
CR Cellera de Ter (CR de les Sèquies del Molí de la Pardina i de la Riera d'Ossor)	Riu Ter
CR de Bescanó (CR del Rec de Baix)	Presa del riu Ter
CR d'Horta de Salt	Sèquia Monar
CR Cervià de Ter, Sant Jordi i Colomers	Sant Julià de Ramis
CR Presa de Viñals	Canal de Vinyals
CR de Sentmenat	Presa de Colomers
CR del Molí de Pals (Sindicat Agrícola Séquia del Molí de Pals)	Resclosa i séquia del Molí de Pals

c. Hydroelectric power production

The study area and the downstream section of the river contain the hydroelectrical power stations listed in **Table 16**. There are two basic kinds of power stations in the area, regulation and run-of-the-river (ROR) plants. While the production of the former depends on the available power in the reservoir, the latter is not related to large impoundments but to the diversion of the river flow. The largest plants in the study area are logically the regulation plants. All them, together with the ROR El Pasteral II are owned and controlled by the Endesa Generación. This private company is allowed to turbinate the flows released from the reservoirs. Among the many involved interests, the primary purpose of the discharge is warrantying the stable supply of drinking water to the urban areas of Barcelona and Girona. However, the particular conditions of the discharge along the three regulation reservoirs are operated by Endesa taking into account considerations of power production.

Table 16 Estimates of average annual production during the perio 1997-2006, according to the PZBT (ACA)

Source: ACA-PZBT; CNE, 2000

Type	Plant	Installed capacity (kW)	Annual production (GWh/year)
Regulation (production depends on the reservoir level and the turbinated discharge)	Sau (2 p.u.)	36 000	22.5
	Susqueda (3 p.u.)	85 000	138.09
	El Pasteral I (1 p.u.)	6600	7.54
Run-of-the-river (using water flows released by El Pasteral I)	El Pasteral II	1685	1.34
	Anglès (Les Fàbriques)	782	0.99
Run-of-the-river (turbines using water flows of the river)	Bonmatí	700	1.98
	Vilanna	440	0.95
	Bescanó	820	1.56
	Grober	753	1.45
	Montfullà	294	0.74
	Salt-1 (Gassol)	368	0.74
	Salt-2 (El Molí)	340	0.80
	Casas (Aurora II)	330	0.95
	Mitjans	100	0.29
	Torras Hostench	334	2.65
	Flaçà (Molí d'en Vinyals)	330	1.05
	Molí de Pals	90	0.556

In terms of the zebra mussel invasion this information is relevant for two reasons. First, it helps to clarify the kind of damage that can be expected due to the different possibilities to manage the infrastructure in response to detection of the invasion. Second, it helps to identify possible impacts in terms of the productions if the utilities are affected or the water flow changes due to zebra management practices.

The water flow scheme for the hydroelectric use is similar in both the Sau and Susqueda reservoirs. The water is taken from a fist tower with sluice gates at three and four different depths respectively. The suitability for human consumption of the physicochemical conditions of the water determines the level of sluice gate that is used for the water extraction. From there the water is transferred to the tower controlled by the electric company, which diverts the water flow to the power station. For instance, in the case of the Susqueda reservoir (**Fig. 20**), the water is transferred 3 km downriver through a pipe crossing the mountain. Thus, the vulnerable points along this process had to do with the devices in contact with the water along this way (grills, pumps, pipes and valves).

Fig. 20 Pathway of the water diverted for power production in the Susqueda reservoir

Source: Own elaboration. Images by Wolrdatlaspedia and ICC.

d. Recreational activities: navigation

As explained above, recreational activities are a main driving force of zebra mussel dispersal. Recreational actors are in direct contact with the environment and contribute to the transport of this and other aquatic alien species.

The Catalan Water Agency is the authority in charge of ruling navigation activities in the study area. In this respect, the following regulations and guidelines were relevant for this context.

- Technical studies for the planning of the recreational use of the reservoirs (ACA, 2005, 2004).
- Regulation in force relative to the classification of reservoirs regarding navigation (DOGC, 2012);
- Technical guidelines in the declaration of responsibility for navigation in the Internal Basins of Catalonia (ACA, 2014d, 2009b);
- Draft regulation for the canoeing in the IBC (ACA, 2007).

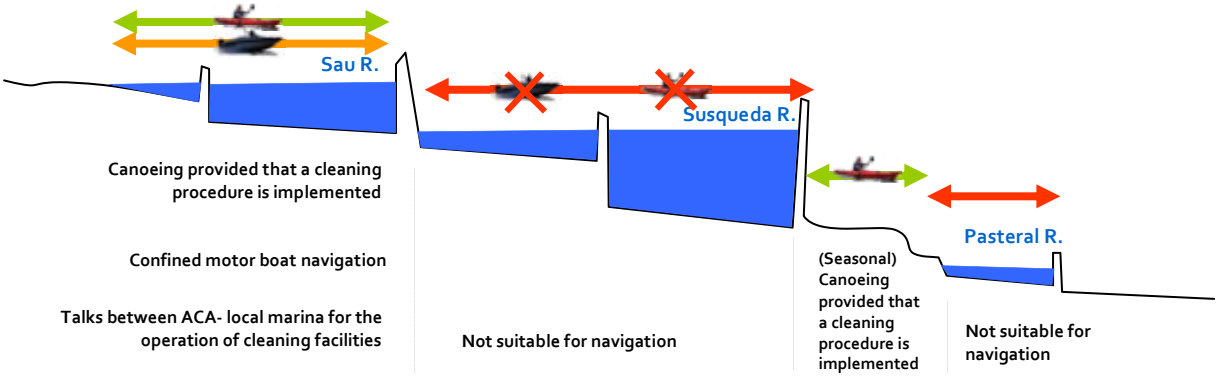
It is worth saying that, as a result of the research process reported in this dissertation, the two last documents included information on preventive measures regarding the zebra mussel invasion. In particular, the preparation of the technical guidelines involved the interaction with different societies of aquatic recreation, a process that is considered a part of the participatory research activities in this thesis.

In synthesis, the current situation of the navigation activities in the study area is represented in

Fig. 21. In the area, only the Sau reservoir is considered suitable for motor boat navigation (but confined in its area). Due to the role of the reservoirs as source of drinking water supply, motor boat navigation in the other reservoirs is restricted to the strictly necessary to undertake water quality monitoring procedures. Canoeing is possible in the Sau reservoir and (seasonally) in the river section between the Sau dam and the tail end of the Pasteral reservoir.

Fig. 21 Navigation in the reservoirs of the Ter study area

Note: Green: itinerant navigation allowed, with cleaning procedures; Orange: navigation confined within the water body; Red: navigation not allowed. Source: own elaboration (based on regulation in force and technical studies mentioned in this section)



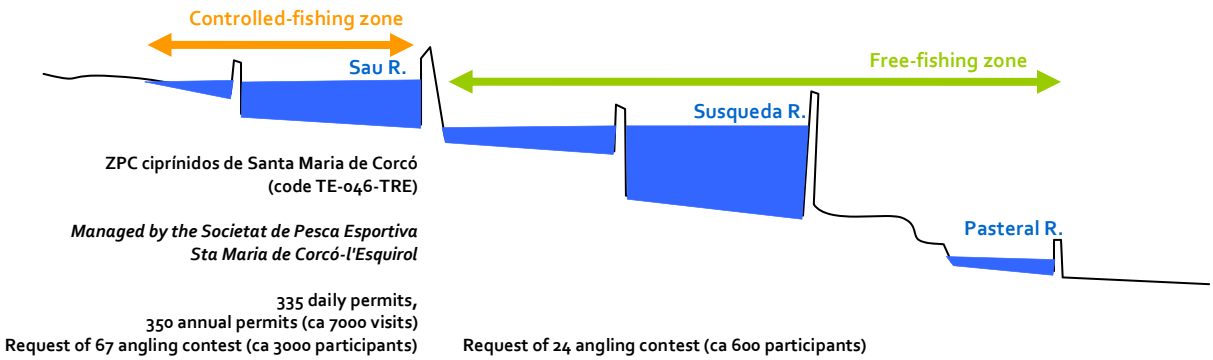
e. Recreational activities: angling

The study area comprises two angling zones shown in **Fig. 22**. The first zone is a controlled-fishing zone, that is, anglers fishing in this area must get a specific permit besides obtaining the annual licence. The figures of attendance provided by the DGMN, based on data from 2010, indicate a permanent flow of anglers coming to this area attracted by cyprinids. The largest number arrives during the period from May to September due to the celebration of angling contests. Downriver from this area there is a free-fishing zone, which any angler with an annual license can access. This makes it difficult to assess the fishing pressure in this area. The only available data is a lower number of angling contests in relation to the zone upriver.

None of these areas is a catch-and-release zone. However, there is interest from the Catalan Angling Federation to transform the free-fishing zone in a so-called 'angling landscape'. This is a provision that would allow the co-management of certain zones with the aim of consolidating sports angling. In practice, this would mean that certain alien species of particular interest for this activity (e.g. *Esox lucius*, *Micropterus salmoides*, *Oncorhynchus mykiss* or *Salvelinus fontinalis*) would be excepted from the obligation of killing, as now it is required by the regulation in force.

Fig. 22 Angling in the Ter study area

Source: own elaboration (data by DGMN, 2010 (Joel Capdevila, com.pers.))



As explained in **Section 1.2.2**, in Catalonia, authorised fish restocking in both controlled and intensive fishing zones are planned annually by the environmental authorities. During the last years there has not been restocking in the study area. However the fish fauna in the reservoirs includes a number of alien species (**Table 17**), throwing evidence of illegal fish translocation in the past. Already a decade ago, in the Sau and Susqueda reservoirs alien species dominated both in species richness (100 percent y 87,54 percent respectively), and in biomass abundance (Armengol and Navarro, 2003). There is not data availability on the situation of the Pasteral reservoir, although several alien species have been detected also there.

Table 17

Alien fish species in the reservoirs of the study area

Source: Armengol and Navarro (2003), complemented by Enric Aparicio (Pers. Com.), based on interviews with local anglers (information kindly provided by M. Real (URS) in 2009

Species	Sau reservoir	Susqueda reservoir	El Pasteral reservoir
Alburnus alburnus			
Barbus graellsii			
Cyprinus carpio			
Lepomis gibbosus			
Micropterus salmoides			
Rutilus rutilus			
Silurus glanis			

1.4.5 Summary of the case-studies: a tale of two dams

The situation in the two study areas that has been presented, the lower Ebro and the Ter, clearly differs from the environmental and administrative points of view. However, both share key commonalities – outlined here – that configure the management context. The rivers in both areas suffer intense hydromorphological alterations imposed by the construction of relatively big dams. Both dam systems (Mequinensa-Riba-roja-Flix and Sau-Susqueda-El Pasteral) are strategic for the provision of services (respectively, energy supply and water supply) for the benefit of users mostly outside the study areas.

In both cases, the construction of these dams enabled a new economic profile for the local residents based on water-recreation businesses, while the traditional ones were suppressed. In principle this seems more marked in the Ebro (with an international projection) than in the Ter (where the reported revenue for these businesses is small). Despite this, key recreational user lobbies in Catalonia, both related with angling and with navigation, manifest a persistent interest in maintaining and expanding these uses in the Ter.

At the same time, the hydromorphological alterations imposed by the dams changed the river ecosystems, creating better conditions for fish species different than the ones present in Mediterranean rivers. European catfish was one of these new species that can be found now in both areas. The consideration of this species as an alien is the same in both regions, but in the Ebro, *Silurus glanis* is not only seen as an economic asset for recreational exploitation but it is also legally recognised as such, since its catch is tolerated and even restocking is allowed in certain areas under certain conditions. This does not happen in the Ter, where this fish – clearly introduced there because of angling practices – is nonetheless known as an alien species that must be controlled, the 'how' still remaining as an open question.

In both regions, the drivers of introduction of the damaging *Dreissena polymorpha* operate, although the invasion does not seem to have taken place in the Ter River yet. Given the detection of larvae and adults in other water bodies of the IBC, this invasion may be imminent. The detailed examination of the factors driving such process is studied in the following chapter.

Observing the problematique from a level closer to the local context provides insights different from those at the Catalan scale, let alone the Spanish or the European scales. At the regional level there is a more straightforward view of the invasion processes as unwanted events. This view is influenced by bioinvasion science and the management mechanisms come given by regulation and planning of control measures. Over time, this position has found a better resonance in the public at large, which is becoming increasingly aware of the presence of alien species as a problem for biodiversity and for water quality. Al the local levels, however, it is possible to notice divergent views about IAS that range from alarm about the damages caused to indifference, or event to fervent defence of some species with positive economic effect in local economies.

2 Multi-level driving forces of biological invasions

Given the emphasis put on preventive policies (CBD, 2002), a better understanding of processes driving bioinvasions is a requirement for policy formulation. To this end this chapter attempts to provide greater insight into driving forces and pressures on biological invasions expanding on the multi-level character of such processes. The discussion emphasizes how preventive policies and actions (responses) against bioinvasions can be underpinned through the involvement of relevant stakeholders linked to major driving forces and through the use of pertinent indicators at different governance levels.

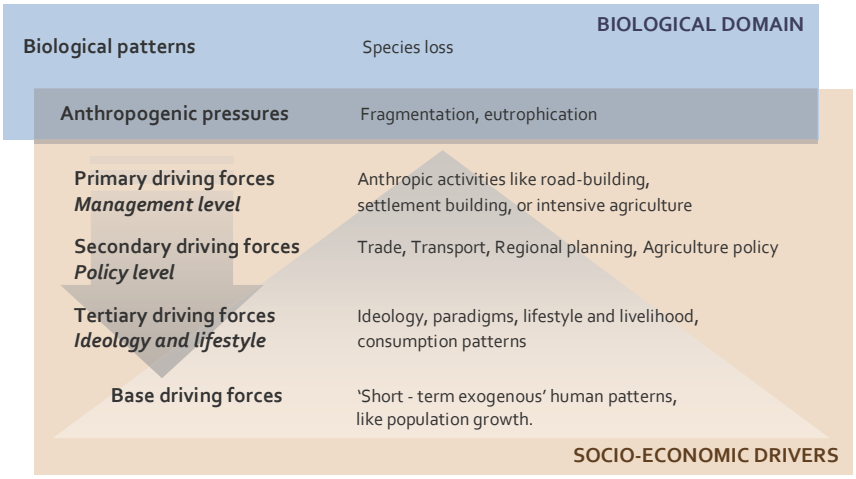
2.1 Examining generic driving forces of biological invasions[9]

The idea of a multi-level character of factors influencing bioinvasion processes can be associated with the dimensions and levels of reflexive governance proposed by Voß and Bornemann (2011) who distinguish three levels of interaction to construct governance designs: micro (focal processes), meso (comprehensive policy programmes) and macro (fundamental values and forms of political organisation). This idea was expanded according to a scheme of interacting driving forces (**Fig. 23**) adapted from Spangenberg (2007).

Fig. 23

A scheme for organising driving forces of biological invasions

Source: Adapted from Spangenberg (2007).



Herein the definition of each level of driving force responds to the need for distinguishing different areas of intervention around two criteria: a) the direct translation of the driving force into a pressure on biodiversity and b) its influence on long-term societal behaviours. Thus, some economic activities directly become pressures on the biological domain. They can be called 'primary driving forces' and correspond to the level of management. Being more flexible in the short term, they receive a permanent influence of structural aspects of the social organization, like the policy level ('secondary driving forces'). In the long term, the most relevant influence comes from the level of ideology and lifestyle ('tertiary driving forces'). Finally, the level of 'base driving forces' includes structural aspects, trends influenced by social decisions only in the long term (e.g. demographic patters). This scheme should not be interpreted as a hierarchy of levels but as a set of interacting domains connected through a variety of interfaces that can be useful in terms of policy making. In this respect, it is close to the 'four spheres' framework described by Maxim et al. (2009). The scheme can also serve to undertake a systematic scrutiny of driving forces.

Environmental history provides examples of adverse effects of the biotic exchange between continents because of the European conquests. In this respect Crosby (1972) and Melville (1997) report the dramatic

[9] This section develops and partially reproduces the argumentation and the tables by Rodríguez-Labajos et al. (2009).

consequences of the European species' arrival in the Americas. The classic work of Charles S. Elton (1958), *The ecology of invasions by animals and plants*, opened the field of research on biological invasions. Since then, many ecology or biogeography studies have analysed factors of successful invasions, taking into account either the ecological traits of the species, the characteristics of hosting ecosystems, or both. Ecological differences between plant invaders and native species (Pyšek et al., 2004), behavioural flexibility (Sol et al., 2002) or the strength of association with the species assemblage that characterizes a particular region (Worner and Gevrey, 2006), are among these ecological factors. In fact, a review of quantitative studies recognized up to 23 characteristics that predispose a species to become an invader (Kolar and Lodge, 2001). This is relevant in terms of risk analysis, as some species traits can be used to assess potential invasiveness, as it will be shown in **Section 4.1**.

Table 18 Selected studies analysing causes of biological invasions

Type of study	Employed methods	Study	Code	Taxonomic group	Scale
Static analyses	Regression analysis	(Case, 1996)	1	Vertebrates (birds)	International (islands)
		(Cassey et al., 2004)	2	Vertebrates (birds)	International
		(Dalmazzone, 2000)	3	Plants	Internationall
		(Dehnen-Schmutz, 2004)	4	Plants	National (site based)
		(Gido et al., 2004)	5	Vertebrates (fish)	Regional (site based)
		(Levine and D'Antonio, 2003)	6	Plants, insects and molluscs	National
		(Lonsdale, 1999)	7	Plants	International (site based)
		(McKinney, 2002)	8	Plants and vertebrates (fish)	National (site based)
		(McKinney, 2006)	9	Vertebrates (birds, mammals, herptiles)	International
		(Pauchard and Alaback, 2004)	10	Plants	Regional (site based)
		(Pyšek et al., 2002)	11	Plants	National
		(Sol et al., 2002)	12	Vertebrates (birds)	International
		(Taylor and Irwin, 2004)	13	Plants	Regional
		(Vila and Pujadas, 2001)	14	Plants	International
		(Westphal et al., 2008)	15	Several	International
	GIS & correlation analysis	(Dark, 2004)	16	Plants	Regional
		(Lundgren et al., 2004)	17	Plants	Regional
		(Pino et al., 2005)	18	Plants	Regional
Process-oriented studies	Dynamics of spatial patterns (mapping)	(Delisle et al., 2003)	19	Plants	Regional
		(Gilbert et al., 2004)	20	Arthropods (insects)	National
		(Herborg et al., 2003)	21	Arthropods (crustacean)	International
		(Johnson and Padilla, 1996)	22	Molluscs	National; International
		(Kraft et al., 2002)	23	Molluscs	National
		(Meinesz et al., 2001)	24	Plants (algae)	International
		(Pyšek and Prach, 1995)	25	Plants	National
		(Sharov, 2004)	26	Arthropods (insects)	National
		(Thresher et al., 2003)	27	Arthropods (crustacean)	National
		(Weber, 1998)	28	Plants	International
	Experts assessment (workshop mode)	(Campbell and Kriesch, 2003)	29	Several	National
		(Chapman et al., 2001)	30	Several	National
		(US OTA, 1993)	31	Several	National
		(Wittenberg and Cock, 2001)	32	Several	International (small island focus)
	Narratives of invasion trends (with or without statistics)	(Bax et al., 2003)	33	Aquatic species	International
		(Carlton, 1996)	34	Aquatic species	Regional; National
		(Carlton, 2003)	35	Aquatic species	International
		(Galil, 2000)	36	Aquatic species	International
		(Grigorovich et al., 2003)	37	Aquatic invertebrates	Regional
		(Eritja et al., 2005)	38	Insects	International
		(Holmgren, 2002)	39	Plants	National
		(Hulme et al., 2008)	40	Several	International
		(Karatayev et al., 2003)	41	Molluscs	Regional
		(Karatayev et al., 2007)	42	Molluscs	International
		(Kraus and Campbell, 2002)	43	Vertebrates (amphibian)	Regional
		(Kowarik, 2003)	44	Plants	National
		(MacIsaac et al., 2001)	45	Aquatic species	Regional
		(Mihulka and Pyšek, 2001)	46	Plants	International
		(Minchin and Gollasch, 2002)	47	Aquatic species	International
		(Pienimäki and Leppäkoski, 2004)	48	Aquatic invertebrates	Regional
		(Panov et al., 2007)	49	Aquatic species	International
		(Pyšek and Prach, 2003)	50	Plants	National
		(Ruiz et al., 2000)	51	Aquatic species (invert. & algae)	National
		(Sytsma et al., 2004)	52	Aquatic species	Regional
		(Whinam et al., 2005)	53	Plants	Regional

Anthropogenic mechanisms underlying the invasion are mentioned only in some of these studies. Heger and Trepl (2003) emphasize that technical and economic developments, cultural preferences and fashions are causes of invasion success that cannot be analysed by the methods of natural sciences. This, together with the lack of data (Kowarik, 2003), perhaps explains the scarce research on the socio-economic origins of biological invasions.

Trying to fill this gap, this section discloses socio-economic factors driving biological invasions based on a cross-taxa screening and selection of studies that considered elements of human agency to analyze invasion success. The review is based in ex-post assessments and not results based on prediction models, and deal with different geographical scales. As result of the search 53 studies were identified and classified (**Table 18**).

The set of reviewed documents included 18 studies considered as static analyses and 35 studies exploring the processes underlying the invasion. The former researched those variables correlated with different indicators of IS richness or abundance, while the later analysed the course of the invasion by means of mapping, qualitative assessment or narratives of the invasion process. Regarding the scale, 20 studies are international, 16 national, 14 regional and 2 studies are multi-scale. Some refer to the kingdom Plantae (20 studies). The kingdom Animalia is represented by 16 studies related to vertebrates (6), arthropods (6) and molluscs (4). Most of the studies for this later *phylum* are focused on the same species. The remaining studies focus on other aquatic species – either invertebrates (2) or not specified (8) – or general or aggregated analyses (7).

In the next page, **Table 19** classifies the findings of these studies in relation to driving forces of bioinvasions indicating their effect on the invasion process (promoting introduction [I], release [R] or establishment [E]), as well as the taxonomic group most affected by the driver.

This way of displaying information presents biological invasions as multi-causal phenomena in which drivers operate at different levels and at different spatial scales. **Table 19** shows that the connections between ecological and socio-economic dimensions are considered as anthropogenic pressures (like creation of invasion corridors) and also as management practices that favour biological invasions. Less often, analyses deal with the role that policies and base driving forces play.

The focal point of the studies related to the drivers in the ground is a certain taxonomic group, or a certain species within. Factors related to the introduction of the species are more studied than those linked to the release and establishment. Most studies emphasize either the invasiveness of the species or the invasibility of the ecosystems (Kolar and Lodge, 2001; Pyšek et al., 2004; Williamson, 1999) and not their relation. Or, rather, they deal with management practices and primary driving forces and not with the socio-economic system that fosters the invasion process, although "*it is not species but socio-biological networks that are invasive*" (Robbins, 2004; see also Bright, 1999). In other words, although invasiveness and invasibility refer to biological attributes of the species or the ecosystems and studying them explain us *how* the invasions take place, the set of socio-economic driving forces are the ultimate reason *why* bioinvasions occur.

Table 19 Socio-economic driving forces and pressures of biological invasions

Note: * Effect: I: Introduction; R: Release; E: Establishment; **Taxonomic group: IV: Invertebrates; P:Plants; F: Fish; Pg: Pathogens, V: Vertebrates; In: Insects; B: Birds; S: Seeds; AS: Aquatic Species; A: Amphibians; M: Mammals; SNS: Several not specified

	Code of the reference	Factor		Effect *			Tax. Group**
				I	R	E	
Anthropogenic pressures	34	**Changes in donor regions or emergence of new ones**		+			AS
	1, 2, 5, 8, 10, 12, 28, 30, 34, 36, 43, 49, 50, 51, 53	**Arrival of propagules and accumulation of propagule banks**		+		+	P, In, AS, F, A, B
	17, 29, 30, 31, 39, 46, 50	**Landscape fragmentation**				+	P
	1, 18, 17, 30, 31, 34, 39, 42, 44, 46, 49, 50, 52	**Changes in disturbance regimes, like changes in fire regimes or pollution**				+	P, AS, B
	22, 23, 26, 30, 34, 47, 48, 51	**Changes in the availability of factors that limit invasions**				+	P, AS, F
	10, 22, 23, 29, 34, 36, 37, 41, 45, 48, 49, 51	**Creation of invasion corridors (aquatic, terrestrial)**		+		+	P, AS, F
Primary driving forces: Anthropogenic activities / *Management level*	29, 31, 32, 34, 47, 53	**Transport practices**	Containerized / packed shipping of freight (e.g. Styrofoam coolers)	+	+	+	P, IV, AS, F
	21, 22, 31, 32, 35, 36, 37, 40, 44, 45, 48, 52		Switch from ballast soil to ballast water in 1800s	-			Pg, In, P
				+			AS
	20, 29, 32, 33, 34, 35, 36, 37, 40, 44, 47, 49, 52		Changes in transportation modes (air, water, terrestrial) and related pathways: wheels, cargo, cabins, ballast water, hull fouling, structures, dredge material, all kind of vehicles	+	+		Pg, AS, In, P, IV, V
	22, 23, 33, 34, 37, 38, 41, 48, 49, 51, 52		Increased size and speed of the commercial shipping	+	+		AS, IV, In
	21, 34, 36, 37, 45, 49		Changes in the available ports and shipping routes	+			P, AS
	32, 33, 38, 40		Generation of debris	+			In, P, AS
	31, 38	**Trade activities**	Importation of used tires	+			In
	29, 32, 38, 43		Increased plant trade (nursery trade, cut flower trade)	+			P, IV, A
	2, 24, 29, 32, 36, 37, 40, 47, 51, 52		Importation of non-food animals (for aquaculture, pet/aquarium, bait, research) and food animals	+	+		Pg, P, IV, AS, B, V
	32, 44		Importation of raw materials as wood or timber	+	+		Pg, P, S
	32		Aid trade	+			IV
	22, 24, 31, 32, 33, 38, 41, 42, 45, 47	**Travel and tourism**	Increased rate of transit via recreational boats and airplanes	+	+	+	In, M, B, AS
	29, 31, 32, 53		Increased number of air passengers and transportation of luggage, plants and animals for leisure, and travel consumables	+	+	+	P
	7, 11, 14, 50 , 53		Increased number of visitors to protected areas			+	P
	23, 32, 39, 40, 44, 50	**Changing agricultural practices**	Introduction of new species for agriculture and forestry	+	+	+	Pg, P, IV, AS, V
	25, 17		Abandonment of field land			+	P
	31		Integration of forestry & agricultural enterprise			+	P
	31		Improvements in threshing and harvesting machinery	-			S, P
	31, 32		Development of new plant species to replace shrinking traditional supplies of wood	-			IV
	30, 44, 50		Forestation (commercial forestry, agroforestry, social forestry)	+			P
	19, 20, 25, 30, 32, 40, 43, 44, 52		Horticulture and ornamental plants / contamination of nurseries, germoplasm banks	+	+		Pg, P, IV, A
	32, 44		Use of non-indigenous plants for soil improvements	+	+		P
	21, 27, 30, 31, 32, 33, 35, 36, 37, 40, 47, 48, 49, 51, 52	**Fauna management**	Aquaculture activities, angling and watershed management	+	+		Pg, IV, AS, V
	30, 40		Appeal of acclimatization societies and fauna improvement	+			Pg, P, IV, V
	21, 30, 32, 39		Introductions for food or hunting purposes (specially in islands)	+	+		Pg, P, V
	30, 31		Domestication of "microlivestock"	+			Pg
	25, 30, 39, 44		Plants cultivation for forage or beekeeping	+	+		P
	10, 16, 17, 18, 19, 29, 30, 31, 32, 44, 46, 50	**Expanding human-made infrastructure**	Expanding network infrastructures such as road and railways			+	P
	21, 23, 27,31, 32, 18, 36, 37, 41, 42, 44, 47, 51, 52		Expanding hydraulic infrastructures such as inter-basin transfers, dams, canals and "constructed wetlands" for wastewater treatment	+	+	+	P, IV, AS
	1, 12, 17, 18, 20, 44, 46, 48, 50		Urbanization and (sub)urban development			+	P, B, AS
	31	**Option for invasive species control**	Side effects of environmental remediation using bacteria, algae	+	+		Pg
	31, 32, 40, 43, 51, 52		Further development of biological control	+			P, IV, A, AS, V
	24, 26, 31		Improvements in pest eradication methods			-	P, IV, AS
	31, 34		Upgraded ballast water exchange systems, and anti-fouling paints	-			AS
	31		Improvements in detection equipment at ports of entry	-			Pg, S

Table 19 (cont) Socio-economic driving forces and pressures of biological invasions

Note: * Effect: I: Introduction; R: Release; E: Establishment; **Taxonomic group: IV: Invertebrates; P:Plants; F: Fish; Pg: Pathogens, V: Vertebrates; In: Insects; B: Birds; S: Seeds; AS: Aquatic Species; A: Amphibians; M: Mammals; SNS: Several not specified

	Code of the reference	Factor		Effect *	Tax. Group**
Secondary driving forces: Policies *Policy level*	31	Political transformation	Increased cross-border movement (material, refugees) due to regional wars	+	SNS
	31, 34, 42		Genetic exchanges between previously isolated regions due to political boundary changes or changes in the political systems	+	S, AS
	30, 31, 42	Trade policy	Expanding volume and network of international links, including international trade and travel	+	SNS, AS
	30, 32, 34	Changes in regulatory frameworks	Promotion of multilateral treaties and laws	+	AS
	31, 38, 47		Free trade agreements	+	In, AS
	31	Agricultural policy	Changes in agricultural, horticultural and forestry enterprise (& practices)	+	SNS
	33	Environmental policy	Slow international progress in response to IS	+ +	AS
	43, 50		Lacks in regulation of major recognized pathways	+	P, A
Tertiary driving forces: Ideology, lifestyle	6, 15, 30, 31, 38	Global developments	Globalisation of economies and trade	+	P, In, SNS, M
	30		Globalisation of the forestry / agro-forestry enterprise	+ + +	In
	30, 31, 35, 42		New patterns of immigration and tourism	+	AS
	31, 32, 40		Wars and military movements	+	SNS, AS, V
	31		Economic interest in few profitable species	+	SNS
	3, 13, 14, 30	Domestic economic trends	Increasing production and development indexes	+ + +	P
	3, 14, 15, 30		Increasing level of imports	+	P, SNS
	2, 31, 47, 30	Emerging social interests and concerns	Increased interest in exotic pets	+ +	AS, B
	30, 31		Increased interest in smaller pets in urban areas	+	F, B
	30, 31, 43		Continued interest in new ornamental plants and animals	+	P, A
	30, 31		Broadened interest in ornamental uses of indigenous plants	- - -	P
	30, 31		Increased concerns regarding risks of chemical pesticide use	+	SNS
	7, 11, 31	Changing perspectives in environmental protection	Increased interest in protecting endangered species	-	P, AS
	30		Changing perspectives regarding alien species	-	SNS
	31, 32		Increased interest in planting forage for wildlife	+ +	P
	43, 52		Bioethical conflicts	+	A, AS
	29, 40	Knowledge / information	Increased need for information: increase demand of mail, internet, shipping companies	+	SNS, P, AS
	30		Growth and maturation of invasion ecology into a robust science	- -	SNS
	40		Ignorant possession	+	Pg, P, IV, V
	31, 33		Progress in genetic engineering	+ +	AS, F
	30, 40		Improved communication methods (internet, global databases) and shared resources		SNS, P
Short - term exogenous	1, 4, 9, 23, 5, 8, 11, 16, 20, 30, 42, 46, 50	Human population dynamics (size and length of occupation)		+	P, F, B, V, In, AS, A, M
	18, 30, 48, 49, 53	Global climate change		+	P, AS

The recognition of a multi-level array of driving forces also evidences that isolated intervention at a certain level may not be sufficient to tackle the problem efficiently. Interventions in the last link of the chain (e.g. aquaculture business, use of pest control methods, etc.) make sense to respond to specific cases. However, if fundamental policies or lifestyle trends remain unchanged, the re-emergence of the initial invasion process is likely. For instance, despite the existing knowledge about the invasiveness of alien aquatic plants, actions to tackle international trade of invasive plants are vain efforts while there is an increasing social interest in ornamental exotic species for aquarium or gardening.

From the findings of the literature gathered in **Table 19**, analysis of pathways can be synthesized in sectoral economic trends whose evolution is crucial to understand new invasion processes. The different studies cited demonstrated that **increase of transport due to trade and travel**, new globalized patterns of consumption and the transformation of hosting ecosystems emerge as main drivers of biological invasions. The kind of pressure is different between sectors. While trade and transport increase the

movement of the species, some other activities enhance their establishment by transforming the ecosystems, especially the construction of transport networks or hydraulic infrastructures such as dams.

International trade and related policies are major driving forces. Ensuing measures for national protection against adverse effects of IS include the Agreement on the Applications of Sanitary and Phytosanitary Measures (the SPS Agreement), signed in 1994 during the negotiations of the World Trade Organization (FAO, 2000). It allows members to restrict international trade to protect human, animal or plant life health from pests and diseases, as long as the restriction is necessary and scientifically justified. Since SPS is a trade agreement, it encourages methods that have the smallest effect on trade (Andow, 2003). Taking into account the increasing flow of material trade the presumption of safety should be employed with caution. For instance, the EU imports per capita per year from three to four tonnes of materials. Imports exceed exports by 500 to 1000 m tonnes per year (Schütz et al., 2004). As a consequence, EU is specially exposed to the introduction of IS, not only due to the introduction of bulk materials but also because of the high level of traffic associated to their transport.

Additionally, people's transportation involves the transport of species. Routes of travellers and transport of passengers are also 'road map' atlases for IS. Travel is also related to infrastructure development, like in the case of the waterways that result in aquatic corridors. This not only makes possible the movement of the species but also disturbs the ecosystems, promoting the establishment of the invaders. Several aspects of environmental degradation facilitate the establishment of IS, like the transformation of coastlines, suburban development (Hulme, 2006) or other changes in land use.

One key primary driving force is the **management of flora and fauna** such as forestry, agriculture, horticulture and gardening, aquaculture, angling, the pet and aquarium industry and the leather industry (see particularly Chapman et al., 2001). These economic activities contribute either to spread the species or to modify the ecosystems. Many of them have other effects, since they appropriate a part of the primary productivity (Haberl et al., 2004) and introduce biological 'pollutants' as GMO (Binimelis et al., 2009a; Wolfenbarger, 2000).

In the end, driving forces associated with invasion processes cannot be separated from underlying socioeconomic development trajectories. For instance Binimelis et al. (2009b) conclude that the emergence and spread of glyphosate-resistant johnsongrass in Argentina as a foreseeable 'side effect' of the rural development model related to the institutional setting, the new agrarian organization of space, and export driven economic growth. They show that responses towards the invasion have been delayed because of reluctance to accept the uncertain outcomes of a new technology. Thus, often management depends on individual strategies that transfer risks to society and the environment.

Then, the way social and technical uncertainty (as discussed by Rauschmayer, 2003) is tackled has implications concerning the type of responses adopted and the type and degree of attention received. For instance, as shown in **Chapter 3**, not all the effects of alien species are perceived as negative from a utilitarian point of view. By the same token, some damaging species have been more researched than others and this is reflected in the state of knowledge about driving forces as well. Driving forces associated with the less-studied species will not be well known.

In any case, as discussed by Binimelis et al. (2007) perception about IS is heterogeneous, context-dependent and dynamic. Therefore, looking into the interactions at the various levels of DF will require broadening the system of analysis and the incorporation of a reflection on uncertainty and ignorance. The logical next step is then to analyse this in depth. In the case of the species considered as case-studies in this dissertation this was done based on participatory methods.

2.2 Driving forces of the invasions in local and regional contexts

In concrete cases studies, knowledge on local driving forces is crucial for the identification of factors that can be managed along the different stages of an invasion process. In this respect, at least two different stages should be distinguished:

- A pre-invasion context (consistent with an *ex ante* evaluation) prevails when the driving forces for the invasion are already operating, but the introduction has not taken place yet. This is the moment when precautionary policies emphasize the need of prevention. The more intense operation of the drivers, the higher potential of introduction, and the bigger risk of invasion. Both *Silurus glanis* and *Dreissena polymorpha* are at the pre-invasion stage in some regions of Spain. The analysed case study in the Ter River, is a pre-invasion context for *D.polymorpha*.
- A post-invasion context (consistent with an *ex post* evaluation) appears when the invasion process already started, as in the Ebro River for the two species mentioned above. A precautionary policy should rely here on abating the progression of the species (mitigation) or reducing its impacts (adaptation). Although early response is advisable, in many cases late reaction is the common response, even when there are irreversible effects involved.

Although in this chapter this distinction will be used for simplicity, as it will be argued in **Chapter 4**, there might be a need for fine-grained typology of stages in terms of management. This chapter compiles information about driving forces in a post-invasion context (the Ebro River) to understand how the invasion of *D.polymorpha* may percolate to other regions that are currently in a pre-invasion context. A discussion will follow on the use of knowledge about driving forces in policy making.

2.2.1 Driving forces of bioinvasions in the Ebro: an invasional meltdown, unveiled

Methods

The driving forces of the invasions were analysed through participatory methods (in-depth interviews, focus groups and participatory observation) (Binimelis et al., 2007b; B Rodríguez-Labajos et al., 2009b). Among them a workshop reported by Rodríguez-Labajos (2006) particularly contributed to the systematic data gathering and classification in the post-invasion context of the Ebro River. Unless specified otherwise, the source of information in this section is that workshop. As the final purpose of the activity was scenario development, the details on participants' selection and organisation of the workshop is described in detail in the corresponding chapter (**Section 4.3.1**).

Results

When stakeholders in the Ebro were requested '*what are the factors influencing establishment, perception of the impacts and the kind of response to the invasions of the zebra mussel and European catfish in the Ebro river?*' they offered, through a brainstorming, the list of factors in **Table 20** and **Table 21**.

According to the participants, common drivers of both invasions involve the severe modification of the water bodies due to the creation of dams enhancing invasibility, and the growth of recreational activities. Introduction of both species is related to previous human-induced alterations in the river ecology. The construction of dams for electricity strongly affected hydro-morphological characteristics of the low Ebro River since the 1960s. For the case of Wels catfish, the species was introduced after other angling-related alien fish released in the new reservoirs in order to promote sports angling, a growing activity due to increasing income and tourism. International anglers, attracted by these fish, pondered the feasibility of

importing Wels catfish into the region and justified it, by the excess of other alien predators lacking a controlling species.

Table 20 Factors influencing the invasion (introduction, impacts, response) of *Dreissena polymorpha* in the Ebro River

Source: own elaboration

Social	Economic	Environmental	Institutional	Technological	Lifestyle
Failure to comply with sailing and angling norms Lack of public knowledge of the species (impacts and dispersion mechanisms) Water use for population supply Non-controlled use of piers Social perception of the invasive species	Water use for energy production (hydroelectric / nuclear) Recreational uses of the water Water use for primary economic activities (predominant except in Flix and Fayón)	Changes in the configuration of the watershed (construction of reservoirs) Changes in the configuration of the watershed (water level of the reservoirs, flow) Vulnerability of threatened species (*M. auricularia*) Vulnerability of sites of community interests. Degradation of the river banks Introduction or reintroduction of fish species Difficulties in the eradication of the species Natural introduction / spread (birds) Water quality	Lack of a clear administrative / institutional responsible Gaps in the regulatory scheme Scarce mechanisms for inspection / control Political use of the case	Use of living bait Boats with equipment for transporting alive bait and prays Unprepared water collection and distribution systems	Popularization / diversification of leisure time (increase of recreational demand) Increase in the traffic of boats Lack of prevention culture and environmental education Lack of knowledge of the territory

Table 21 Factors influencing the invasion (introduction, impacts, response) of *Silurus glanis* in the Ebro River

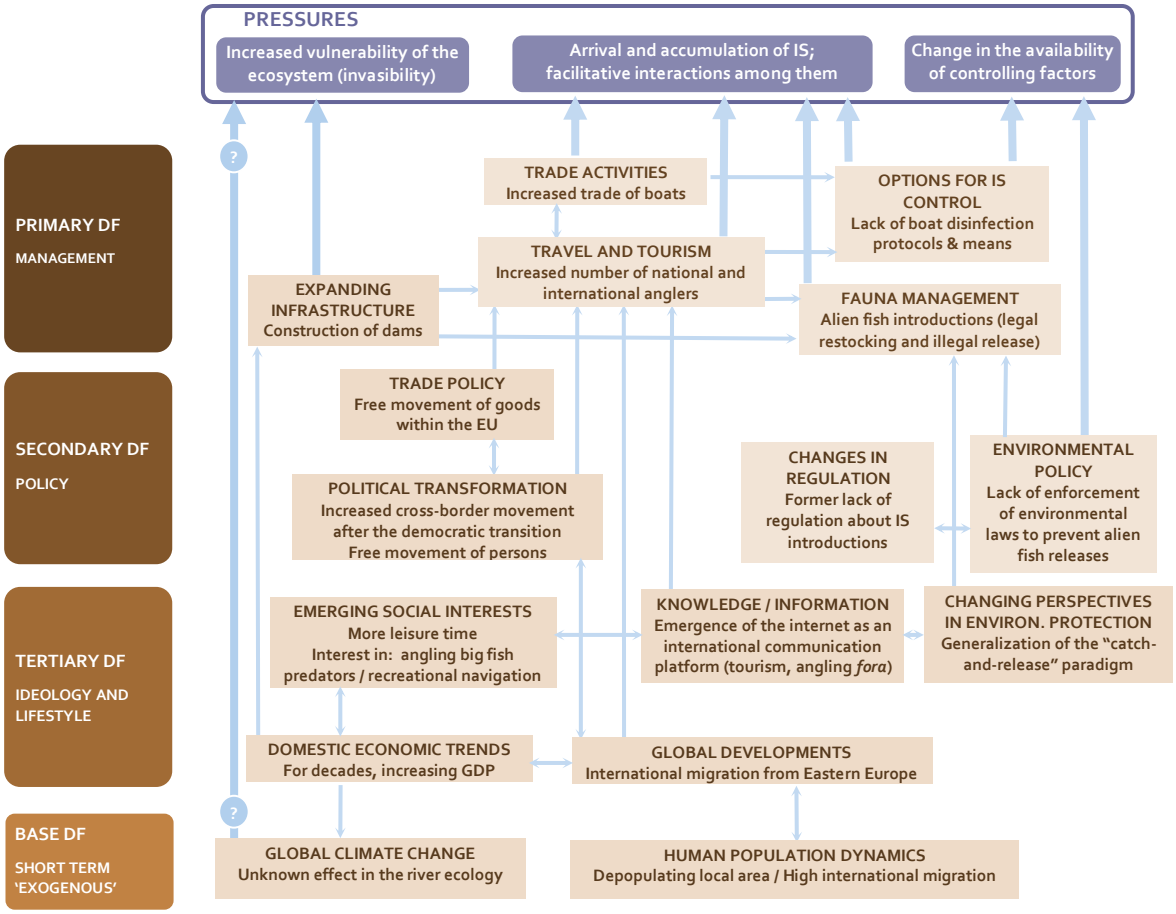
Source: own elaboration

Social	Economic	Environmental	Institutional	Technologic	Lifestyle
Arrival of foreign workers with non-traditional fishing practices Arrival of foreign anglers Population aging and low demographic density (demographic regression)	Growing importance of the aquatic recreational activities (angling, sailing, mechanic workshops) International renown of the area due to angling activities Concentrated income for tourists activities (4 international tour operators subcontract local companies) Hatcheries of introduced species Use of the river by external actors	Changes in the configuration of the watershed (construction of reservoirs) Lack of knowledge about the ecology and biology of the species, and the ecosystem Not controlled practices of ecosystem management (illegal introductions) Deliberate introduction of species for biological control Floods Simultaneous increase in the presence of the introduced alburno and decrease of native madrilla (species used as bait)	Gaps in the regulatory scheme Scarce mechanisms for inspection / control Mechanisms for allocation of fishing permits	Use of living bait Information exchange about the regional angling possibilities (by the internet) Problems in the final disposition of dead fish (hygiene)	Preference for angling of big predators Bio-ethic conflicts (angling with/without death)

In the case of the zebra mussel, angling of Wels catfish was unanimously identified as the catalyst for the introduction. *Silurus glanis* is not the only fish species introduced for sports angling in this region, but certainly it is the most paradigmatic, and it plays a major role to brand the area as an 'angling paradise'. The traffic of boats and the surge of international anglers – enhanced by free trade and free movement of persons in Europe – not only sustained new fish introductions but were also the likely cause of the accidental release of the highly damaging invasive bivalve. In particular, the hitchhiking of the zebra mussel larvae during the deliberate introduction of an exotic fish used for bait (bleak, *Alburnus alburnus*) is highlighted as the most likely pathway. This cyprinid was introduced after the decrease of the native species employed for the same purpose (French nase, *Chondrostoma miegii*). The accidental release of the zebra mussel larvae probably took place in this way in the mid-1990s in the Riba-roja reservoir. From there, craft traffic and the deliberate translocation of living fish presumably transferred larvae and adult specimens to new water bodies.

Fig. 24 Multi-level driving forces and pressures of aquatic bioinvasions in the Ebro River

Source: own elaboration



Coming back to the scheme or multi-level driving forces presented above, the set of factors driving this process, as well as the exerted pressures, and the linkages among them pointed out by the participants are shown in **Fig. 24**. This organisation of the factors is inspired by the participatory system dynamics approach as described by Videira et al. (2010), which unveils conceptual models depicting the interrelations *of the structure underlying the unsustainable trends that characterize a persistent problem or sustainability issue*.

In the Ebro, stakeholders clearly associate the invasions to multiple and interactive causes, operating at various scales. Responsibility of 'foreign' actors was underlined in the case of both species. External users of the river's ecosystems pushed the local environment by demanding alterations in the river basin and by transporting organisms. This exerted a constant pressure that eventually modified the hydro-morphological and biological quality of the Ebro River. There is an agreement among stakeholders that the release of zebra mussel was one of these pressures. As argued above, the proliferation of the European catfish is also seen as a pressure (for instance, in the pressures-impacts analysis made for the implementation of the WFD). However, some actors regard the introduction of the fish as a management measure that responds to their recreational interests towards the river.

In fact, an emergent property of bioinvasions studied in the Ebro is that they seem to be interlinked (Rodríguez-Labajos, 2006). As described above, introduction of the *S.glanis* in the Ebro relies on the pre-existing abundance of other alien fish; its maturity might have been facilitated by the presence of American red crayfish (Carol et al., 2009); its angling fostered fish introductions as a living bait and possibly the accidental release of the zebra mussel. In addition to the promotion of macrophytes' growth, not clearly demonstrated and even scientifically contested (Ibáñez et al., 2008), this bivalve is the vector of the parasite *Phyllodistomum folium*, previously unknown in Spain (Palau and Cía, 2006).

The invasion chain may not stop here. Increasing evidence points at facilitative interactions between the invasions of *D.polymorpha* and the dramatically damaging *Dikerogammarus villosus* (killer shrimp) due to enhanced habitat complexity and provision of food material through biodeposition (Gergs and Rothhaupt, 2008). This amphipod has not been detected so far in the Iberian Peninsula. However, the association of its invasion with the spread of zebra mussel spread is so strong that the presence of zebra mussel was used to assess the general risk of *D. villosus* invasion in the UK, the most recent invaded area in Europe (Gallardo et al., 2012). Therefore the watershed authorities should already have in mind the possible arrival of the killer shrimp to Iberian waters.

Simberloff and Von Holle (1999) developed the concept of **invasional meltdown** to describe this kind of facilitative interactions among alien species. After examining the situation of the Great Lakes over the past 200 years, Ricciardi (2001) concluded that an invasional meltdown rather than biotic resistance characterize those aquatic ecosystems. The hypothesis is controversial, but there is a mounting quantity of empirical studies that support it (Green et al., 2011; Grosholz, 2005; Jeschke et al., 2012).

Possibly in the Ebro, the invasional meltdown has transformed the river ecosystem in an irreversible way. It is only hoped that the same process will not take place in other Iberian basins. It must be noted that the invasions have taken place in an ecosystem that had already been heavily modified, being part of what the political ecologist Paul Robbins (2004) calls human 'preparation of landscape' as a prerequisite for the invasion. When the good ecological potential of the reservoirs (rather than status) has to be defined according hypothetical parameters, the political decision, based on advice from natural scientists, has been to interpret the abundance of fish invaders as a downgrading attribute. This decision is justified by the vague indications of the WFD in this regard but those actors who do not regard the *S.glanis* as an unwanted organism disagree with it. However, it is important to take into account the set of ecological 'pre-conditions' and implications of the introduction of invasive big fish in terms of their linkages to other unwanted organisms. The supporters of introducing alien fish species in the river ecosystems either do not understand or deliberately ignore these linkages. We have often heard in the field –or rather in the river– Central European fishermen telling us, with a smile, that the zebra mussel was brought in by birds.

The 'interlinked invasions' view implies a strong criticism to angling-related practices based on alien fish predators. In spite of the social and economic benefits that they provide to the area, they ecologically impoverish the river by exerting pressure on local species that are valued little. Eventually, the ecological homogenization is a result of a utilitarian, market-based view of natural resource management.

Hierarchy of driving forces of bioinvasions in the Ebro

During the initial workshop of 2006 stakeholders were requested to organise the driving forces of bioinvasions according to both their uncertainty and their relevance. A driver is more uncertain as far as its evolution is less predetermined and thus less predictable; that is, what happens with this factor is not set in stone. Relevance of a driver is defined in terms of its importance for explaining why the facts have taken place in a certain way.

There was considerable agreement between the participants in spite of the different points of views represented. The agreed classification of factors is shown in the next page (**Fig. 25**).

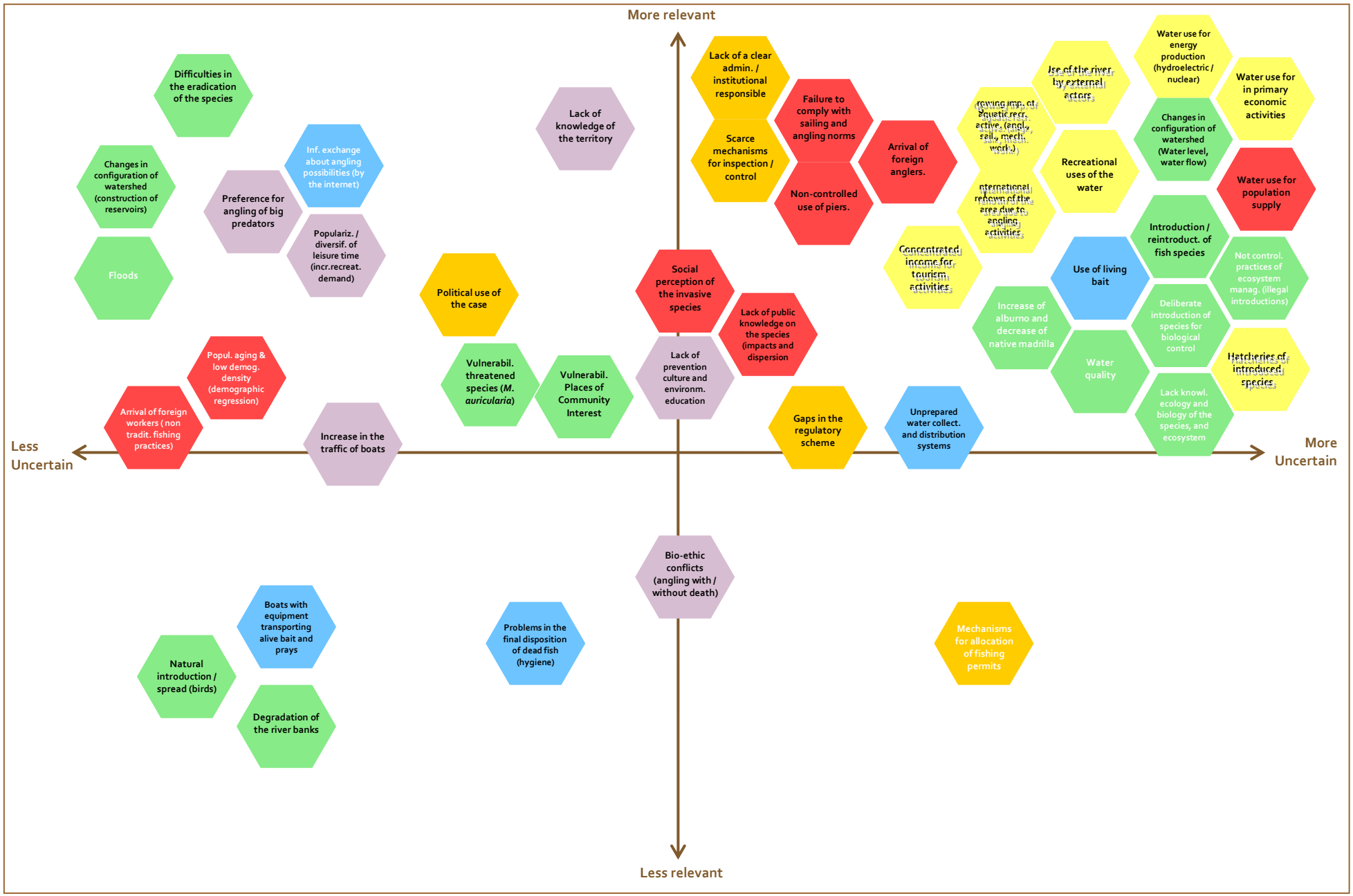
Stakeholders' appraisal, also summarised in **Table 22**, deemed that the most relevant drivers of the invasion processes are linked to environmental constraints, like the difficulty of eradication of the species, or to the poor knowledge of the territory by the population, the lack of means for the institutional response and types of river use, especially those carried out by external actors. Uncertain topics include practices of ecosystem management like illegal introductions of alien species and those changes in the hydrological conditions of the river that can be managed like the water level and the water flow.

Table 22 Hierarchy of driving forces, according to stakeholders

Source: own elaboration

Less relevant factors	Givens Relevant and predictable factors	Key uncertainties Relevant and unpredictable factors
Environmental odds	**Environmental constraints**	**Administrative / normative framework**
Natural dispersal of the invaders (by birds)	Difficulties for eradicating invasive species	Institutional coordination
Degradation of the river banks	Vulnerability of endangered species and protected areas	Administrative and legal gaps
	Hydromorphological alterations (dams)	Control and inspection mechanisms
		Knowledge of the ecosystem
Angling management	**Socio-demographic facts**	Public information
Allocation of fishing permits	Aging population and low demographic density	
Problems in the final disposition angling wastes	Political use of the case	**Water use management**
		Management of the water level and water flow
Bioethics conflicts regarding catch-and-release practices.	**Larger-scale trends**	Recreational use of the dams and kinds of angling practices
	Increasing recreational demand (popularization and diversification of leisure time)	Adaptation of infrastructures for irrigation and domestic supply
	International migration and arrival of non-traditional angling practices (preference for fish predators)	
	Information exchange (internet)	

Fig. 25 Classification of driving forces according to stakeholders in the Ebro: relevance and uncertainty



2.2.3 Towards a generic classification of driving forces of the zebra mussel invasion in Catalonia

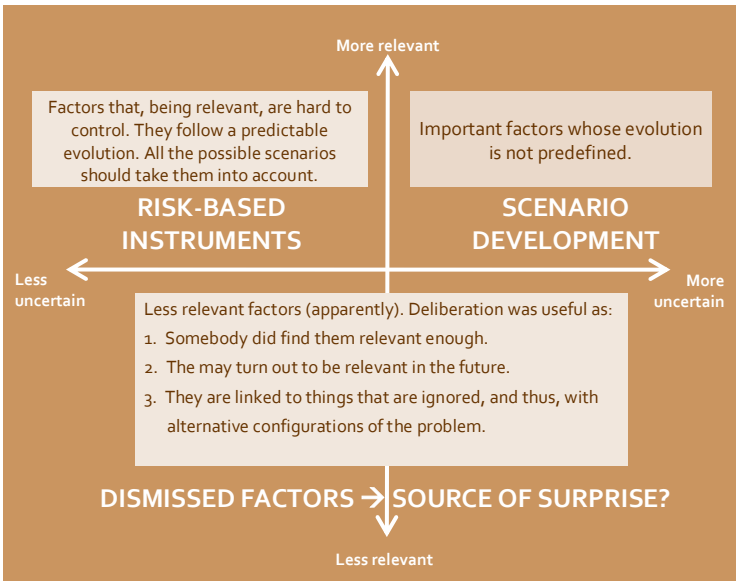
The recognition of the perceived relevance and uncertainty on the drivers made by the stakeholders in the Ebro allows distinguishing three significant possibilities around factors driving biological invasions. Each one has different analytical implications that have been sketched in **Fig. 26**.

This section analyses information organised around these three typologies, using the case of the zebra mussel as an illustration. The objective is to offer an overview of the factors of the invasion that can be used for its management in Catalonia, both in a post-invasion and in a pre-invasion context. In the scheme of driving forces presented above, this would focus on the primary driving forces related to management.

The source of information, in terms of the considered factors, is the participatory process in the Ebro, together with additional data collected through the interaction with other experts along the period 2006-2010. A particularly valuable development for the systematisation of this information was the supervision of a report updating the susceptibility index to the invasion of the zebra mussel in Catalonia in 2009. The report was commissioned by the ACA to Anhidra (www.anhidra.com), an environmental consulting firm codirected by Dr. Imanol Cía, author of the first thesis in Spain about the management of zebra mussel. The results of that study will be described in **Section 4.1** to exemplify the use of risk assessment in the context of the zebra mussel invasion in Catalonia.

Fig. 26 Analytical implications of classifying relevance and uncertainy of driving forces

Source: own elaboration



The novelty of the results presented in this section is the proposed structure and the link of such structure with the formulation of management proposals. The types of factors stemming from the classification of driving forces for the introduction, establishment and socioeconomic impacts of the invasion, and their specific occurrence in the case of Catalonia are displayed in **Table 23**. Note that the terminology employed for uncertainty analysis relies on the analytical frameworks proposed by Wynne (1992) and Stirling (2007).

Table 23 Factors in the invasion process of zebra mussel and ensuing management measures

Source: Own elaboration

Type of factor	Introduction	Establishment	Socio-economic impact	Management measures
Risk factors (predictable, difficult to control)	Location and connectivity of water bodies	*Limiting factors*: Calcium concentration pH *Non-limiting factors:* Water temperature Trophic state	Existence of infrastructures that are difficult to adapt (water supply, irrigation, hydroelectric power production) – permanent damages in infrastructures and associated productions	Consideration of criteria or conditions related to such factors in the rest of management measures
Uncertainty factors (changing dependent on stakeholders' decisions, manageable)	Accessibility to the shoreline Traffic of motor boats and trailers from colonised areas Traffic of canoes from colonised areas Authorised fish restocking from risk areas Use of tackle employed in colonised areas (fishing nets, waders, …) Seaplanes, helicopters and other means for forest-fire control Introduction due to the use of sub-aquatic equipment (e.g. neoprene wetsuits) Introduction due to the use of equipment for research, monitoring or maintenance (e.g. multiparameter water quality probe)	*Non-limiting factors*: Water level oscillation Residence time	Development of recreation activities, scientific research and maintenance works without restrictions of use / access Existence of adaptable infrastructures (for water supply, irrigation, hydroelectric power production) – temporal damages in infrastructure and associated productions Existence of run-of-the-river hydroelectric stations – production loss because of water flow change Development of management measures – related control costs	Controlling access to the shoreline – Preparation of guidelines for the restricted access to the reservoir Planned water level oscillation and water flow Ban to hull and bilge cleaning in direct contact with the reservoirs Regulation of navigation practices Regulation of angling practices and related activities (e.g. fish restocking) Regulation / good practices codes for the recreational use different to navigation and angling (swim, diving), as well as scientific activities, monitoring and riverbank maintenance works Guidelines for the use of reservoirs during forest fire control Strengthening communication and surveillance
Ignorance factors (unknown, possible emergent properties)	Illegal fish translocations Malicious deliberate release Natural transport of the species (e.g. by birds) *Which factors can modify unexpectedly the possibilities of zebra mussel introduction?*	*Which factors can modify unexpectedly the possibilities of zebra mussel introduction?*	*Which impacts can emerge unexpectedly after the introduction and establishment of the zebra mussel?*	Research, filling the knowledge gaps, surveillance Strengthening stable communication channels between all involved actors

First, predictable (less uncertain) drivers will appear in every possible configuration of the problem at hand. A good knowledge of the physico-chemical characteristics and of the species biology allows identifying elements that are crucial to explain the course of the invasion, but are difficult to modify through management measures. An example would be the connectivity of a reservoir with another that is already colonised by the zebra mussel. Such elements must be considered as given. Since both their attributes and their role in the invasion process are well known, such factors fall under the strict definition of **risk factors** (were both the outcome and the probability of the event are known).

They set trends, aspects of the future that are known from the present. Mitigation measures can be justified on the basis of risk-based instruments. An example would be to restrict mobility of itinerant boats during the periods when the water temperature reaches parameters that favour the zebra mussel reproduction.

Still, adaptation strategies are the most advisable management action toward these factors. This is related to the reduction of impacts, although there are impacts that do not depend on the actors' behaviours or the management decisions. They are mostly related with the existence of infrastructures that are prone to suffer damages by the colonisation of the zebra mussel and that cannot be adjusted or their adaptation is not technically (or economically) feasible in the short term. Their vulnerability to impacts is higher. Therefore, rather than specific measures to transform such factors, their consideration in management comes from the establishment of criteria or conditioning standards in the implementation of other measures. Thus, in the case of an infrastructure which adaptation is not possible, its protection should be a priority in case it is being decided where to focus restrictions in de development of recreational activities. **Section 4.1** expands on the use of risk-assessment tools for the preventive management of alien species in Catalonia, with a particular reference to the use of these tools for the management of the zebra mussel.

Second, relevant factors in which evolution is not predetermined arise as *key uncertainties* of the invasion process. There are relevant factors shaping the course of the invasion that depend on decisions of stakeholders and hence are subject to change in the short and medium term. Actually such factors are susceptible to be influenced through management measures and cannot be assumed as given. This is the case, for example, of all the variables related to the recreational use of the reservoirs. The circumstances of their past can be described, but their future is unknown to certain extent. They depend on personal decisions, linked to lifestyles and diverse social and economic conditions.

The probability of each factor occurring, and the specific way how it is going to affect the course of the invasion are not necessarily known *ex ante*. In principle the intensity of angling activities may be associated with a higher propagule pressure. However a big angling society whose members have an environmentally respectful behaviour may result less harmful than the effect of a small group of anglers showing scant concern for the ecological status of the aquatic ecosystems.

Such **uncertainty factors** are then fully includable in the management model. In fact, they are the main object of management itself. On the one hand they relate to measures for mitigating the invasion, such as the prevention of the introduction controlling the accessibility of boats and other equipment to the shoreline or reorganising angling-related practices. Prevention of the establishment

is also possible by adjusting to a certain extent environmental conditions such as the water level or the residence time of the reservoirs. On the other hand uncertainty factors can be part of adaptation measures aiming at reducing impacts.

The recognition of the manageable features on the different river uses indicates how and when an intervention is more effective to reduce impacts of the invasion. This involves the adaptative operation of all kind of water management infrastructures, not only to avoid their damage but also the associated impact in productions or service provision (e.g. hydroelectricity or irrigation). In the same vein, measures to prevent the invasion may have an indirect negative effect in the development of activities previously developed without any restriction, such as recreational navigation or riverbank maintenance works.

A way to include uncertainty factors in support of management is developing scenarios, since this focus attention on those relevant factors whose evolution is not predetermined. In the Ebro case, the precautionary approach justified the choice of scenarios as a fundamental analytical tool to understand the evolution of the invasions. This process is explained in detail in **section 4.3**.

Third, some factors can be dismissed because they are not perceived as relevant. Still, their detection is useful to indicate alternative visions of the problem. In addition, sometimes the problem at hand suffers from irreparable gaps in sound scientific knowledge (e.g., how and where was exactly the zebra mussel introduced in the Ebro?) or even knowledge gaps that the involved analysts and stakeholders are not aware of.

Such instances can be described as **ignorance factors**. As little attention is paid to them, they might deliver emergent properties of the process. Due to their nature, codifying ignorance factors is not easy. Still, in the case of zebra mussel invasion some elements can be seen under this perspective. For instance, little is said about malicious deliberate releases of the species as a possible pathway of dispersal. Natural dispersal by birds is systematically argued by anglers a dispersal mechanism, and systematically ruled out by scientists and policy makers.

From the point of view of their role in uncertainty assessment and their consideration in management, recognising ignorance factors may help to explore sources of surprise. For instance, they can be a way of generating shock scenarios, helpful as resilience tests for the implemented management strategies. By definition these factors are hard to control and then there are not specific measures managing them. Still improving the communication between the involved actors to better identify sources of ignorance can be a way to deal with them.

All the factors play a role in the evolution of the process. It is difficult to achieve a complete understanding of the course of action focusing only on predictable factors through the use of risk-based instruments. In this way, those aspects that are a matter of reflexivity and social learning are hard to incorporate. Scenario development may prove helpful for this purpose, but eventually will need risk assessment if the aim is using scenarios for practical purposes. In the end, the methodological choice is that which is most suitable for framing the problem. This will be addressed in detail in **Chapter 4**.

2.3 Integrating driving forces in policy making and the role of local agency

The previous sections have emphasized the idea that analysing socio-economic driving forces of biological invasions is a requirement for developing preventive policies. In this respect, some efforts made in the past (Dalmazzone, 2000; Vila and Pujadas, 2001) rightly searched for the human roots of biological invasions. However, these studies failed to recognize the multi-level constituents of human agency driving bioinvasions. As a result, their crisp results – linking invasion success to gross domestic product (GDP) or to the Human Development Index (HDI) – were consistent in terms of the statistical methods employed, but highly misleading for policy making. To reduce GDP or to push down the elements of the HDI would be like using a machine gun to kill a (certainly dangerous) mosquito. In contrast, the multi-level frame presented above allows a better understanding of the causal networks behind biological invasions, and gives a better indication of how to respond to invasions in the appropriate terrain.

2.3.1 Multi-level action is required …

Biological invasions, as well as their driving forces, operate at several scales and levels. This is similar to other environmental phenomena (like chemical pollution) whose impacts can be better assessed at the local scale but whose driving forces can be outlined at different levels of human involvement. Specifically, increase of some trends at the regional or global scale (trade, tourism) and recurrent local patterns in different countries (urbanization, fragmentation of ecosystems) contribute to make of biological invasions a global environmental problem. Thus, responses will depend on the level at which the action is required, helping in the design of policy and management options.

The multi-level scheme of driving forces presented above reveals different terrains of action in the management of invasive species. When preventive management relies on the analysis of final pathways, only the last link of the chain can be grasped and dealt with. Coming back to the aquatic invaders in the Ebro, deliberate fish introductions can be better surveyed if it is recognized that they come associated to angling practices and actors. However the responsibility cannot be simply attributed to the anglers but also to the set of conditions that frame their activity, like the touristic profile of the region, the construction of dams, or even the lifestyle of a society that downsizes the human relation with aquatic biodiversity to its direct use for leisure.

Using the terms posed above, the actors at the management level are influenced by those at the policy and the ideology/lifestyle levels. Still, policies aiming to prevent and control biological invasions will not reach implementation if this is not of interest to the actors at the management level. Stakeholders impaired by biological invasions may push to promote nature conservation or to implement IS control. But not all stakeholders will be prone to participate in control responses. Moreover, in some cases, like the angling of exotic fish species, disagreement is to be expected since the invasion process is actually an essential aspect of such activity.

The framework proposed in this chapter helps to map stakeholders' responsibilities and the necessary spheres of intervention by enhancing a systematic review of performances at the different levels. This mapping provides a pointer for enhancing governance of responses to bioinvasions, through enhanced monitoring, risk management and communication, and public deliberation on preventive actions.

First, organizing plans to tackle bioinvasions must consider the interaction of groups of interests that often operate at levels beyond the policy maker's scope of influence. It is not likely that such plans are of equal relevance to all groups. When biological invasions are agreed as unwanted events, the argument of the common enemy may trigger a focal response against damaging invaders, often related to accidental releases. That seems to be the case of the zebra mussel and also the apple snail that have strong negative economic effects. Local action may reinforce response capabilities for a preventive management of pathways. But some drivers respond to global trends, like the globalization of the agriculture and forestry business or the increase of tourism and trade.

Local actions by themselves may not have enough repercussion, and an integrated multi-level governance action is required. The inclusion of new preventive principles in the dynamics of these upper-level drivers (policy and ideology) necessary involves actors such as governmental authorities, social lobbies and the educational system. This is particularly relevant when IS richness is not unanimously perceived as negative, like it happens when the introduction of exotic species is inherent to business practice [e.g. in some countries two global invaders like *Eichhornia crasipes* (water hyacinth) and *Corbicula fluminea* (Asian clam) are commercially distributed through nursery and aquarium trade respectively, as it happened in Spain until the publication of the Spanish Catalogue of AIS (BOE, 2011b)]. Likelihood of accidental or even deliberate IS release is high if an informed multi-level action is not undertaken.

Second, the recognition of multi-level driving forces can be used to trace links between groups of stakeholders at the different levels that can underpin coordinated action against bioinvasions. Besides formal institutions, like normative agreements connecting the political sphere and the management activities (e.g. laws forbidding the release of exotic species into the ecosystems), there are groups of stakeholders playing a role at different levels (management, policy and lifestyle). That is the case of professional associations, authorities at the meso level and researchers. They are then key linkages for information exchange, thus bringing new concerns to stakeholders. For this reason, responses to bioinvasions would benefit from these groups' partnership and networking, for instance, through the joint elaboration of sectoral codes of conduct and good practices toolkits. The role of researchers seems to be particularly relevant for interlinking ideology and policy, as it happens with the chemical pollutants (see, for an example, Hulme et al. 2008).

Monitoring is an essential aspect of preventive action. By acknowledging the multiple processes that drive biological invasions it is also possible to plan a fine-grained monitoring scheme, developing monitoring capabilities of key sectors and actors. Any integrated monitoring programme should also be jointly agreed and implemented, motivating responses to questions like: "In which way the process I am related to is contributing to IS introduction and establishment? What kind of measures can be implemented there and how are they progressing?"

2.3.2 … but still, local agency matters[10]

The science of bioinvasions utilizes the term 'agency' meaning the direct human involvement in the different steps of the invasion process (Kowarik, 2003). This involvement is central to qualify such processes as a component of human-induced global change (Lonsdale 1999).

Herein, agency is understood rather in institutional terms. Agency represents the capacity of stakeholders to pursue their own objectives and influence a given situation. Already employed in the fields of psychology, sociology, political science, economics (Bandura, 2000; Elder Jr, 1994; Hernandez and Iyengar, 2001; Hodgson, 2004), the term agency has not been thoroughly introduced in uncertainty analysis yet, although it comes embedded in the analysis of some local conflicts (see, for instance, Urkidi, 2008). As Bandura (2002, 1989) and Colomy (1998) note, agency usually manifests itself through intentional, innovative and purposive transformations, and requires the direct involvement of social actors in shaping or influencing the decision-making process by reacting, if necessary, to external influences. In fact, as also noted by Dolfsma and Verburg (2005), the tension between (social) order and change, the so-called structure-agency relation, has a long history in social sciences (see, for instance, Fullbrook, 2002).

In the Ebro, local stakeholders have specifically mentioned the pressures from external interests when describing the current state of the environment. Therefore, it is possible to argue that the performance of the agency in the community and at different scales of analysis has had significant consequences on the developments in the area.

Bandura (2002, 2000) distinguishes among three forms of agency—personal, proxy and collective—depending on the way it is exerted; either individually, delegated to others or cooperatively. Collective agency relies on the conscious belief in the efficacy of collective action to attain desired outcomes, and is understood as an emergent group-level property beyond the addition of individual capabilities. A clear manifestation of agency is forethought, as it allows actors to anticipate the likely consequences of their aims, set goals and plan their courses of action (Bandura, 1989). Still stakeholders' agency capability differs given local conditions (Ray, 1999).

On several occasions, globally, local groups have shown themselves to be effective in raising awareness and exerting pressure to enforce—or even expand—existing normative boundaries (Walter and Martinez-Alier, 2010). There is also a wealth of literature stressing the fact that grassroots mobilisation is a crucial factor in shaping localities (Esteva and Prakash, 2004; Mollenkopf, 2003). Certainly, local coalitions (i.e. joint action taken by stakeholders in pursuit of diverse but overlapping interests) differ in their capabilities due to local and external conditions. Consequently, while some stakeholders may have considerable lobbying power, be well-versed in interactive action and significantly oppose the system, others may be more easily affected by external influences.

Clearly, it is not possible to appreciate how coalition formation, negotiation and group conflicts impact societal adjustment to changes induced by external driving forces, without an assessment of local agency. Ray's (1999) evaluation of endogenous development in the LEADER Community Initiative,

[10] This section develops and partially reproduces the argumentation by Özkaynak and Rodríguez-Labajos (2010).

and Taylor's (2007) efforts in linking the idea of agency to democratic culture are a few, yet excellent examples in this regard. The link between different interests, and the roles actors play at different scales must also be understood for multi-level governance, a common underlying purpose of scenario development and analysis (Wehrmeyer et al., 2003). This links with the discussion in the first section of this chapter.

Therefore, understanding local collective agency seems to be a prerequisite in coherently combining structural influences at the global and national levels, with potential local-level developments. Although the existing literature on agency emphasizes the importance of capability for collective agency, it does not provide a clear framework to evaluate such agency at the local level. **Table 24** proposes a set of attributes that may be identified as the constituents of local agency capability, i.e. the key aspects that make positive contributions to good performance. There is no evidence on a hierarchical relation among these factors, but instead there are positive feedbacks. These factors support capabilities that, based on pre-existing values and interests, trigger selective associations and drive bigger and enduring (more stable) changes. Thus, they in a way determine the local power to generate effective, non-polarized coalitions, and hence, denote to what extent the local level can respond to larger-scale influences.

Table 24 Evaluation of local agency

Source: Own elaboration

Constituents of local agency	Enhanced capability	Candidate indicators	Performance in the Ebro
Access to information	Awareness	Number of local media (press, radio); on-line platforms	Medium-high
Wealth and resource management	Autonomy	Level and distribution of income; legal, scientific and technological support	Low-medium
Social mobilisation history	Motivation Learning Legitimacy	Public expressions of social conflict, demonstrations, manifestos, letters to parliament	High
Social networking, coordination and lobbying	Operative Self-validation	Richness, abundance, and structure of formal social networks	Medium-high
Citizenship rights	Formal protection	Legal recognition of minorities	High

In the case of bioinvasions in the Ebro, local agency performance was raised as a critical issue to analyse inter-scale interactions. While paying attention to the ways in which international and national contexts can influence the region, it was crucial to understand the level of agency at a regional/local scale as well. From the participatory process in the case study, some attributes have been derived for identifying agency at the local level. They are: access to information, use and management of local and external resources, history of resistance to external impositions, existence of social networks and coordination capacities, and citizenship rights. The agency performance in some cases may be low and/or limited due to lack of concern, coordination, activism, normative support and/or financial resources.

Here, *access to information* refers to the possibility of exchanging up-to-date information inside and outside local borders, thus raising awareness about issues that are of interest. Given the importance of 'information politics' in shaping local environmental agendas, for instance, in environmental struggles

against the damage from oil extraction, gold mining or dam construction, local groups' access to information provided by NGOs or other civil society groups armed with greater information become crucial in creating pressure on powerful actors and pushing more effectively for social change.

As a second element, *wealth and resource management* refers to the control of material and intangible resources to enable autonomous choices. This control is related either to the direct ownership of assets or, access to them through external allies whose interests converge with those at the local level. This factor not only denotes affluence, but also the availability of intangible resources, outstandingly legal, scientific and technological ones. Beyond resource availability, resource distribution may also be a relevant factor in explaining power asymmetries. An example of this can be found in the origins of *La Via Campesina*, an international movement supporting traditional peasants in areas were food sovereignty and agrobiodiversity are pressed by agricultural modernization. Worldwide groups of farmers affiliated to this movement are calling for a permanent ban on the cultivation and importation of genetically modified organisms (GMOs) (Desmarais, 2007). This kind of protest has derived in fact limitations of GMO cultivation in several parts of Europe (see www.gmo-free-regions.org). In the frame of contending European agri-environment discourses on GMOs (Binimelis et al., 2009a), this can be seen as proof of strengthened regional self-determination that is inspiring similar processes in other parts of the world.

Third, *the history of local social mobilization* reinforces motivation and learning. If past social conflicts were successful in the pursuit of local interests, the 'yes-we-can' motto can be substituted by 'remember-we-already-could'. This applies likewise to failed attempts against external pressures. Past failures could generate a negative background that may erode the potential for local agency (e.g. mistrust between local groups). However, the relevance of this attribute resides not only in the recognition of past effectiveness, but also the emergent legitimacy of local coalitions. For instance, according to R. Guha (2000: 107), Gandhi has given to Indian environmentalists their most favoured techniques of protest and moral vocabulary to oppose external pressures. An example here would be the Chipko movement in the 1970s. Inspired by Gandhian activitsts, hill peasants in the Himalayas stopped loggers by hugging the trees. They were nourished by an oral tradition that reminded the actions and leaders of previous protest movements in defence of the forests in the same region during colonial times.

Social networking, coordination skills and lobbying possibilities provide social movements with operative capabilities. The variety and abundance of social networks, whatever their aim, are indicators of activism and provide fertile grounds for collaborative efforts, overall if the structure of such networks allows better exploitation of other factors (information, resources and lessons from the past). Self-validation (ergo self-consciousness) is a significant outcome of local organizations and networks, and thus also underpins the legitimacy of local coalitions. As Kadirbeyoğlu (2004) points out one such example is the armed struggle of the Zapatistas that was launched symbolically on the day NAFTA became a reality. Accordingly, the Zapatista movement not only includes demonstrations at the national level, such as the precedent of the 'march of the ants' – when 400 Chol Indians marched to Mexico City in 1992 – but also has transnational contacts strengthened by international meetings (Morton, 2002).

A final overarching aspect to emphasize is the reliance on *citizenship rights*. The normative and institutional framework must not deprive local actors (or some of them) of equitable access to the benefits of state protection. Only then can local concerns and claims be a part of social debate, on a solid and stable foundation. This aspect is in fact often referred to in episodes of intense local conflict. For instance, in early 2009, the Presidency of Peru managed to promote regulatory changes that enabled oil exploitation in indigenous territories of the Peruvian Amazon, which intensified the ongoing indigenous resistance. Among other matters, the protesters appealed to the International Labour Organization Convention 169, ratified by Peru in 1993, which seeks the informed prior consent of indigenous communities in such cases. After dramatic clashes between the indigenous population and security forces in June 2009, the controversial decrees were suspended. At that time, an indigenous leader reflected on the case using the language of citizenship rights: "*We are as Peruvians as you are, brothers. The country is not only the capital city Lima, but is also the coast, the rainforest and the highlands*"[11] (Jiménez, 2009).

All in all, each of the above aspects can be evaluated on either a qualitative or quantitative basis by looking at the proposed indicators or at others better suited to the case under analysis. Such appraisal allows for distinguishing the situations where capability for collective agency is weak (low) from those where capability for collective agency is strong (high).

In fact, the fieldwork—apart from interests and coalition formation analysis—provides insight into the agency of each coalition at the local level as well. At this point, it is also possible to argue that the interaction with the local level itself can (intentionally) change agentic capability, so the levels ex ante and ex post of the process should be distinguished when exploring possible futures by means of scenarios. In fact, this is why a participatory scenario building is very useful and desirable.

In the Ebro, decision making about local resources has taken place for decades outside the region and for the benefit of external areas, including decisions on the location of dams and dangerous industrial facilities. However, certain key socio-economic, political, and cultural attributes of the region help to characterise the level of agency in the case of Ebro as relatively high.

In terms of access to information, for instance, the region is characterised by many local and regional newspapers and radio stations that address topics directly related to the experiences of the local population. The media is especially active in offering a 'not-in-my-backyard' vision of the region as an entity with its own social and cultural profile. Any news about external pressures easily finds a prominent place in the headlines. Many journalists/newspapers have effectively taken advantage of institutional support (funds for regional development) to adopt new technologies (e.g. on-line platforms), or join consortia of local media from different parts of the state.

Moreover, the defence of a specific dialect of the Catalan language has been traditionally used to define the idea of territory beyond administrative boundaries. This also enhanced the relationship between local residents, and the locals were found to have a high sense of belonging to the region in general.

[11] Original in Spanish: "*Somos peruanos como ustedes hermanos. La patria no es sólo la capital de Lima, es costa, selva y sierra*" (Lidia Rengifo).

It can also be argued that past resistance movements provided fertile ground for the birth of social movements. In the early 2000s, a social network successfully opposed the hydraulic infrastructure mega-project of the Spanish National Hydrological Plan. As explained in **Chapter 1**, that foresaw the extraction of 1050 Hm^3/year from the low section of the river to other Mediterranean river basins (BOE, 2001b). After massive public opposition, the new socialist government withdraw the Plan (BOE, 2004). Strengthening of social networks, such as Plataforma per la Defensa de l'Ebre (Platform for defence of Ebre), supported by a patchwork of local mass media (press and audiovisuals) crucially contributed to this result (see, for instance Valldepérez, 2004). During the episode of draught in 2008, the same actors contested the proposal of a temporal water transfer from the Ebro to the Metropolitan Area of Barcelona (Portal informatiu 3-24, 2008), perceived as a menaces to their political interests. Through this experience, the local level has not only proven to be strong, but also learned to recognise itself as such.

As a result of this relatively high level of local agency, the region is characterised by elements of motivation, legitimacy and operative capabilities. In this respect, stakeholders expressed a need for extending the role of participation of civil society concerning the management of local resources. In this regard, some of the statements from local actors can be used to close this chapter:

"Aquí hi ha dues regions autonòmiques amb diferències legislatives però no diferencies culturals. Qui legisla des de Barcelona marca una normativa des dels despatxos"	*"We have legislative differences but any cultural difference. Who is ruling from Barcelona determines a norm from the desk"*
"Els espais de participació de la societat civil venen donats per la universitat però no a partir de les administracions"	*Areas for the participation of civil society are given by the university but not by the administrations*
"Tenim les ganes (de participar), però no tenim els mitjans"	*We would really like (to participate), but we lack the means*

Communication efforts do not seem to be carried out effectively by the administration in charge of dealing with the response to invaders. In fact, some of the expressed demands by the local level are currently approached by the public administrations, but stakeholders do not perceive them. For instance, during interviews, officers in the different regional administrations and the watershed authority highlighted their coordinated efforts for fighting against zebra mussel. If local stakeholders do not recognize them, either the coordinated decision making is not effective or the persons in charge have not been able to develop proper communication strategies at the local level.

3 Socio-economic impacts of biological invasions

Why is it relevant to study the socioeconomic impacts of biological invasions? A frequent answer is the need of informing decision making. This is a similar view to the common notion that monetising externalities is a requirement to develop economically rational decision making. The economic consequences of some invaders include effects on production, prices and markets, trade, food security and nutrition, human health and finances (Evans, 2003). The idea that estimates of the economic impacts and costs of biological invasions are required to implement reliable management practices and related policies underlies many economic valuation exercises, such as the relatively recent Aukema et al. (2011).

Among the most cited studies are the assessments conducted by David Pimentel and colleagues for the United States (Pimentel et al., 2005, 2000). They estimated the magnitude of the environmental impacts and economic costs (damage and abatement cost indistinctly) associated with the diverse non-indigenous species (NIS) that have become established within the United States. The updated results of the studies set the cost of biological invasion within USA at USD 120,105 m per year, which means around USD 400 per capita per year. Nevertheless, both reports conclude emphasizing the limitations of this approach: '*Precise economic costs associated with some of the most ecologically damaging exotic species are not available*. (…) *If we had been able to assign monetary values to species extinctions, losses in biodiversity, ecosystem services, and aesthetics, the costs of destructive NIS would undoubtedly be several times* [the reported amount] (Pimentel et al., 2005: 282-283)". One step further in this approach is the consideration of the ratio between costs and benefits of IS management measures, as in Barbier (2001). The several limitations of both approaches have been highlighted by Born et al. (2005), who conclude with the advice to *abandon the mono-dimensional approach of monetary evaluation*.

Binimelis et al. (2007a) and Charles and Dukes (2007) were the first attempts at providing an integrative framework to structure the information on IS impacts using the concept of ecosystem services. Along the line of this dissertation, the first study also described how different evaluation methods (risk assessment, cost-benefit analysis, cost-effectiveness, multi-criteria analysis and scenario development) deal with the information about impacts along the management process. A central reasoning of that paper is that valuation is dependent on perception and as such is heterogeneous, context dependent and dynamic. Therefore, we concluded on the need of identifying the stakeholders and their roles as prime perceivers and promoters of impacts: '*Due to the reflexive nature of the invasion processes (new relevant attributes are continuously added to the relationship between people and invasive species), participation of stakeholders in both identification of outcomes and analysis of priorities is needed in the evaluation processes*.'

Based on this idea, new elaborations of the assessment of IS impacts in ecosystem service provision were developed. Born (2008) explored in depth the usefulness of this approach for displaying the scope of possible impacts as well as to reveal the degree of uncertainty about impacts in the measurement procedure. Vilà et al. (2009) made an assessment of the situation in Europe, exploiting the improved cross-taxa IS inventories at the continental scale (e.g. DAISIE project; www.europe-aliens.org). Such a large screening of data also allowed confirming a significant positive relationship

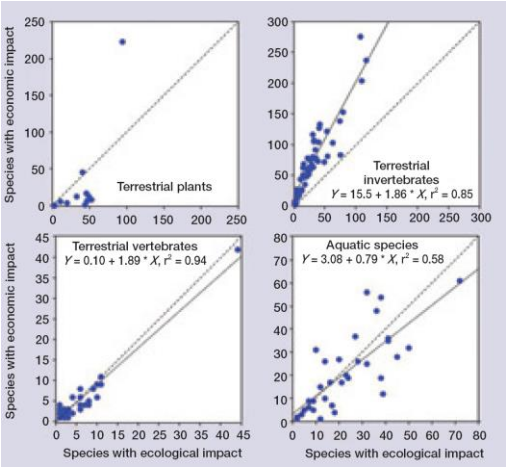
between the number of species with ecological impacts and those with economic impacts, particularly apparent in the case of aquatic species (**Fig. 27**).

Fig. 27

Relationship between the number of alien species with ecological and economic impact per region for different taxonomic groups in Europe

Each data point represents an individual country, major island, or administrative unit (n = 63). The outlier in terrestrial plants and vertebrates represents the United Kingdom. The linear regression for plants is not shown. Dashed line represents the line of unity. Data from the DAISIE database.

Source: Vilà et al. (2009)



This chapter [12] contains various notions on the assessment of the socioeconomic impacts of biological invasions and examines the relationship between impacts and management. Working definitions and developments of the methodological framework to structure the information on IS impacts follow in the next section, which links the above studies to examples of aquatic species both at the EU and at the Catalan level. An overview of the impacts in the case of zebra mussel and European catfish in the Ebro is presented next. Finally, an estimate of possible impacts of the invasion of the zebra mussel in a vulnerable area in the Ter River is offered in the last section.

3.1 Classifying impacts

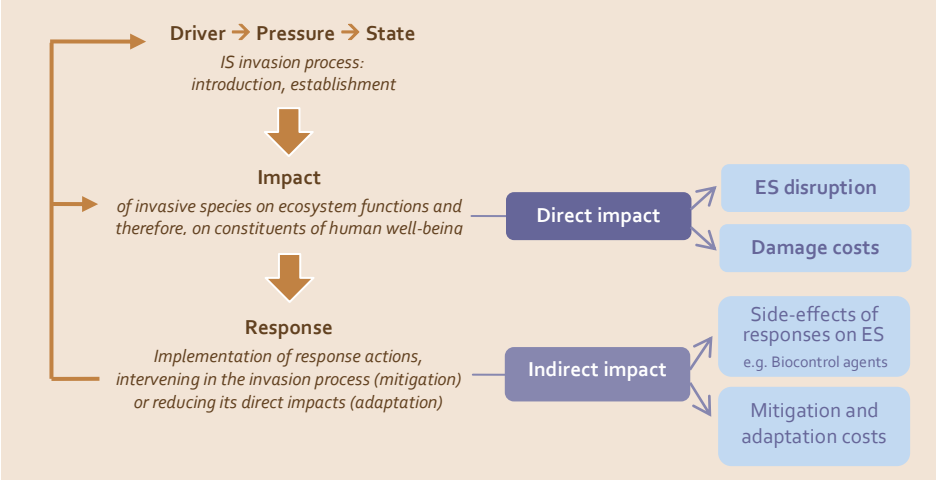
Binimelis et al. (2007a) introduced a distinction between direct and indirect impacts of biological invasions. The former includes direct impairment on ecosystem functions and dependent constituents of human well-being due to the IS introduction and establishment. The latter refers to indirect impacts that stem from the implementation of response actions, such as control costs or side-effects of the introduction of biological control agents, among others (**Fig. 28**). Note that this difference does not refer to the traditional distinction between damage costs and control costs of undesired processes (such as pollution). It rather clarifies the kind of effects of the invasion along its interaction with human interests and choices.

[12] With acknowledgement to discussions with colleagues in different research projects between 2004 and 2010: Jara Andreu and Joan Pino (preparation of the ExoAqua Information System), Kristofer Dittmer (project 'Development of models and technologies for the prevention and control of zebra mussel' (072/SGTB/2007/1.1), and Rosa Binimelis, Wanda Born and Iliana Monterroso (ALARM project, GOCE-CT-2003-506675). Particular joint works are mentioned along the text. Some sections of the text reproduce parts of two publications of which I was the lead author (B Rodríguez-Labajos et al., 2009b; Rodríguez-Labajos et al., 2010).

Fig. 28

Types of direct and indirect impacts of biological invasions

Source: Adapted from Binimelis and Rodriguez-Labajos, 2007



As an illustration, the approach was implemented for the analysis of sixteen freshwater aquatic organisms in Europe listed as the '100 of the worst' by the DAISIE project. They include 10 invertebrates, 3 vertebrates and 3 macrophites (**Table 25**).

On the one hand, by interacting with ecological processes at the genetic, species and ecosystems level, biological invasions modify the provision of ecosystem services (ES), defined as '*the conditions and the processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life*'(Daily, 1997)[13]. As shown with examples next, this may happen as a direct consequence of the proliferation of an alien species, in its interaction with the ecosystem.

For example, the Canadian waterweed (*Elodea canadensis*) creates a dense stands covering wide areas of the water bodies where it is established. In this way it impairs *supporting* and *cultural* services as it alters nutrients availability and reduces the recreational potential of such areas, as boating, fishing and swimming are impracticable. In Catalonia this happened, for instance, in the Utxesa reservoir, as reported in February 2011 by the head of the Torres de Segre angling society (Eduard Escolà, pers. com. 28/02/2011).

Regulating services are impacted in a number of ways. The presence of the particularly damaging Red swamp crayfish (*Procambarus clarkii*) triggers various mechanisms that impair biological control, disease regulation and erosion regulation. As in other parts of the world, the spread of *P. clarkii* in Catalonia has been subsequently followed by the virtual suppression of the native crayfish species, in this case the endangered *Austropotamobius pallipes*. Finally, the losses of *provisioning* services caused by AIS are perhaps the most visible ones for the general public. As an illustration, the toupmouth gudgeon (*Pseudorasbora parva*) generally dominates the fish communities due to resource competition and introduction of pathogens, reducing the productivity of the commercial species.

[13] As Mooney and Ehrlich (1997) review it, the history of the ES notion is more ancient than its well-known formalisation by Daily (1997). However, Daily's contribution, and others' before and since, allowed a scientific agreement on the need of a standardised account of the human dependence of ecosystems. The Millennium Ecosystem Assessment (MA, 2005b, 2003) was the celebrated outcome of such agreement. This dissertation uses the well-known categories proposed by the MA: supporting, provisioning, regulating and cultural.

Table 25 Impacts of selected aquatic inland organisms to ecosystem services in Europe

Source: Own elaboration, based on data from the DAISIE database. The 16 species selected correspond to the section 'aquatic inland species' in the list '100 of the worst' (www.europe-aliens.org/speciesTheWorst.do)

Ecosystem service		Impact description / effect	Species
Supporting services	**Nutrient cycling**	Alteration of food and oxygen availability	New Zealand pigmyweed *(Crassula helmsii)* Asian clam (*Corbicula fluminea*) Zebra mussel (*Dreissena polymorpha*) Canadian waterweed (*Elodea canadensis*) Comb jelly, sea walnut (*Mnemiopsis leidyi*) Brook trout (*Salvelinus fontinalis*)
		Changes in primary production	Brook trout (*Salvelinus fontinalis*)
	Habitat stability	Changes in community structure	Freshwater hydroid (*Cordylophora caspia*)
		Refugia	New Zealand pigmyweed *(Crassula helmsii)* Round goby (*Neogobius melanostomus*) Red swamp (*Procambarus clarkii*) Brook trout (*Salvelinus fontinalis*)
Provisioning services	**Food**	Loss or gain in commercial production and harvest (fisheries, aquaculture)	Swim-bladder nematode (*Angullicola crassus*) Crayfish plague (*Aphanomyces astaci*) New Zealand pigmyweed *(Crassula helmsii)* Zebra mussel (*Dreissena polymorpha*) Chinese mitten crab (*Eriocheir sinensis*) Salmon fluke (*Gyrodactylus salaris*) Comb jelly, sea walnut (*Mnemiopsis leidyi*) Red swamp (*Procambarus clarkii*) Stone moroko(*Pseudorasbora parva*) Brook trout (*Salvelinus fontinalis*)
	Genetic resources	Threat to the viability of endangered / native species	Crayfish plague (Aphanomyces astaci) Red swamp (*Procambarus clarkii*) Brook trout (*Salvelinus fontinalis*)
		Genetic hybridization	Brook trout (*Salvelinus fontinalis*)
Regulating services	**Water regulation and purification**	Choking waterways	New Zealand pigmyweed *(Crassula helmsii)* Canadian waterweed (*Elodea canadensis*)
		Increase in water filtration	Asian clam (*Corbicula fluminea*) Zebra mussel (*Dreissena polymorpha*)
		Bioaccumulation	Zebra mussel (*Dreissena polymorpha*)
	Biological control	Reduction of native species through displacement, predation and resource competition	Fish-hook waterflea (*Cercopagis pengoi*) Freshwater hydroid (*Cordylophora caspia*) Killer shrimp (*Dikerogammarus villosus*) Canadian waterweed (*Elodea canadensis*) Chinese mitten crab (*Eriocheir sinensis*) Round goby (*Neogobius melanostomus*) Red swamp (*Procambarus clarkii*) Brook trout (*Salvelinus fontinalis*)
	Disease regulation	Infection of native fauna/flora	Crayfish plague (Aphanomyces astaci) Salmon fluke (*Gyrodactylus salaris*) Red swamp (*Procambarus clarkii*) Stone moroko (*Pseudorasbora parva*)
		Production/accumulation of toxic substances	Fish-hook waterflea (*Cercopagis pengoi*) Red swamp (*Procambarus clarkii*) Round goby (*Neogobius melanostomus*)
		Vectors of human, livestock and wildlife diseases (e.g. dengue).	Zebra mussel (*Dreissena polymorpha*) Red swamp (*Procambarus clarkii*) Chinese mitten crab (*Eriocheir sinensis*) Swim-bladder nematode (*Angullicola crassus*)
		Injuries	Zebra mussel (*Dreissena polymorpha*)
	Erosion regulation	Intensification of soil/river banks erosion or viceversa	Red swamp (*Procambarus clarkii*)
Cultural services	**Recreational**	Changes in recreational use of natural sites	New Zealand pigmyweed *(Crassula helmsii)* Zebra mussel (*Dreissena polymorpha*) Canadian waterweed (*Elodea canadensis*) Brook trout (*Salvelinus fontinalis*)
		Impairment of eco-tourism activities	Zebra mussel (*Dreissena polymorpha*) Brook trout (*Salvelinus fontinalis*)
Damage costs		Damage to infrastructures and utilities	Crayfish plague (*Aphanomyces astaci*) Asian clam (*Corbicula fluminea*) Freshwater hydroid (*Cordylophora caspia*) Zebra mussel (*Dreissena polymorpha*) Canadian waterweed (*Elodea canadensis*) Chinese mitten crab (*Eriocheir sinensis*) Red swamp (*Procambarus clarkii*)

The direct impacts can also take place on the economic sphere rather than on the ecosystems. This happens when the species damage human-made infrastructures or utilities with loose links to ecosystem service provision. As explained below zebra mussel is a major example. Also as an example of direct impacts on human made infrastructure *P. clarkii*'s digging habits cause water leaking in paddy fields, as very often the rice farmers in the Ebro delta can bear witness.

On the other hand, there are indirect impacts stemming from the measures applied to mitigate an invasion or to develop the necessary adaption to it. Again such impacts can be classified according to the effects in ecosystem services. Indirect impacts are for instance the opportunity cost of economic resources put at the service of control and adaptation.

The examples mentioned here are only some of those presented in **Table 25**. The use of the ES framework allows organising information in a way that is useful for management without falling into reductionism:

- The ES framework allows species that affect a bundle of ES (such as *Proclambarus clarkii*, *Crassula helmsii* or *Dreissena polymorpha*) to be distinguished from species that affect one single service, but with extreme intensity (such as *Aphanomyces astaci*, the crayfish plague or *Angullicola crassus*, the swim-bladder nematode). A proper attention to this can support policy makers to prepare a strategy of interaction with other stakeholders targeting more accurately the right groups of interests who can become allies in the control measures.
- The ES framework also helps to identify the source of trade-offs and ambivalences. The example of the brook trout (*Salvelinus fontinalis*) illustrates this point. The species competes with other native salmonids and predates on amphibians, zooplankton and other invertebrates. In Spain its proliferation aggravates the processes jeopardising the endangered freshwater pearl mussel (*Margaritifera margaritifera*). However, the species has a positive economic impact for local communities due to sport fishing. Although the ES approach has been used here just to identify impacts, it could be used to clarify perceived benefits of AS for some stakeholders. This opens the door to analyse the issue of ambivalence of species, both in socioeconomic and in ecological terms. If the social decision is to control the species, then clarifying the sources of ambivalence should be a first step to understand social conflicts due to AIS control.

3.2 Impacts of IS in Catalonia

As reported in **Chapter 1**, the knowledge on aquatic IS in Catalonia has improved remarkably due to the ExoAqua information system. This effort supports a comprehensive identification of AIS impacts in aquatic ecosystems. To this end, AS species of different taxonomic groups in aquatic ecosystems of Catalonia (both inland and marine) were selected with the information available in May 2011 (which is the same that is available in October 2015). Filters were applied to the original dataset in order to exclude species with the status 'Not introduced', 'Eliminated' and 'Not evaluated'. Also, 'Reports of sighting' in Catalonia of not established species in Spain (most of them birds) were excluded from the analysis. The final representation of species is shown in **Table 26**.

Table 26 AS in aquatic ecosystems of Catalonia, according to their current status

Note: (1) Includes 1 species with status 'Uncertain, close to invasive'; (2) Includes 4 species with status 'Uncertain, close to naturalised'

Source: ExoAqua (May 2011)

Tax-group	Casual	Report of sighting	Introduced	Not established	Established	Invasive	Naturalised	Translocated	Uncertain status	Total group
Diatoms and dinoflagellates	-	-	7	-	-	-	-	-	2	9
Magroalgae	-	1	12	-	-	2	-	-	1	16
Plants	48	2		-	-	42 [1]	83 [2]	-	1	176
Invertebrates	-	-	14	-	8	5	-	-	-	27
Fish	-	2	-	8	9	15	-	6	2	42
Herpetofauna	-	1	-	10	-	2	-	-	-	13
Birds	-	5	-	61	-	5	-	-	-	71
Mammals	-	-	-	1	-	1	-	-	-	2
Total status	48	11	33	80	17	72	83	6	6	356

The final selection includes then 356 alien species. Besides showing their taxonomic distribution, the table also classifies them according to their current status along the invasion process, from the early introduction to the naturalisation state. It is to be underlined that a high number of species (48) are casual[14] plants which presence has been registered in aquatic environments, like river banks. Six species under uncertain status (current knowledge of the species does not allow to determine whether they are alien or not) have been also included.

Available information about impacts of the selected species was organised following the scheme of direct and indirect impacts. This distinction was relatively easy to establish for the costs of human interest. However, there is not available information to elicit indirect impacts on ES and therefore the table includes then only direct impacts on ES. All known effects of each species have been registered. Thus, for example, Asian clam (*Corbicula fluminea*) is impacting regulating services, through effects in biological regulation as it may generate changes in the local abundance, composition or distribution of other mollusc species. At the same time, it is known to impair freshwater provisioning services due to physical damages to irrigation infrastructure, which in turn become economic damage costs. These three effects have been recognised in the respective type of impact. The result of classifying the existing information is shown in **Table 27**.

The same as in the example of the freshwater organisms in Europe (**Table 25**), this framework enables the precise organisation of the variety of AIS impacts. Using the number of species as an indicator, it is possible to point out ES that are particularly impacted.

Looking at the general results, a first observation is that more than 75 percent of the listed species (270) lack a characterisation of impact, either because the existing studies cannot conclude that there is an impact or, more often, because the species' impact has not been evaluated. This is the situation of 59 percent of the alien species from the list. While not established birds or naturalised plants account for a big part of this percentage, the lack of information also affects introduced fish (4 sp), herpetofauna (1 sp), invertebrates (11 sp) and macroalguae (1 sp).

[14] AS that do not generate self-replacing populations.

Table 27 Impacts of alien species in Catalonia (n. sp. = 356)

Note: (A) Number of entries within this category; (B) Entries of impact within this category, in percentage, (C) Entries of impact within this category, in percentage of impacts on ES. Source: Own elaboration

Type of impact		Taxonomic group (number of species)									Total category		
		Diatoms & dinoflagellates	Magroalgae	Plants	Invertebrat.	Fish	Herpeto-fauna	Birds	Mammals	Total	A	B	C
Impact on Supporting services	Nutrient cycling	-	-	11	3	5	1	1	-	21	62	23	24
	Habitat stability	1	2	13	2	8	-	1	-	27			
	Pollination	-	-	2	-	-	-	-	-	2			
	Gene pool protection	-	-	1	2	6	-	3	-	12			
Impact on regulating services	Biocontrol	2	4	34	13	23	3	5	2	86	131	48	52
	Disease regulation	1	-	5	2	1	2	3	1	15			
	Erosion regulation	-	1	1	1	1	-	-	2	6			
	Water regulation & purification	1	-	13	2	7	-	-	-	23			
	Natural hazards	-	-	1	-	-		-	-	1			
Impact on provisioning services	Fibre and fuel			2						2	37	14	15
	Food	-	3	7	5	3	2	4	2	26			
	Freshwater	-	-	4	2	1				7			
	Ornamental	-	-	-	1	-		1	-	2			
Impact on cultural services	Aesthetic	-	-	-	-	1		1	-	2	23	8	9
	Recreational	1	1	7	3	2			1	15			
	Mobility and Transport	-	-	4	1	-		1	-	6			
Damage costs		-	-	6	3	-		1	2	12	12	4	-
Mitigation / adaptation costs		-	-	3	1	2	1	1	2	9	9	3	-
Information gaps	No inform. available	6	11	17	3	15	9	3		64	270	-	-
	Not evaluated	-	1	127	11	4	1	62		206			

Still the 25 percent of species that count on information (86 sp) sheds light on impact characterisation. The higher number of impacts takes place through direct impact on regulating services. This accounts for half the total number of impacts registered, in great part because of disrupted biocontrol services. Impact in supporting services is the next category affected (23 percent), followed by provisioning and cultural services (14 and 8 percent respectively). Although the species that cause costs (either damage or control) are often the focus of the highest public attention, registries in these categories only represent 7 percent of the total number of entries, involving the seventeen species listed in **Table 28**.

Impacts in regulation services offer two interesting insights. On the one hand, the issue of uncertainty is introduced. Impacts in biocontrol and in water regulation and purification include three entries where the attribution of impact was uncertain. That is, there is a potential that the species is causing that particular effect, but the literature does not offer certainty on this matter. Such is the case, for instance, of the *Silurus glanis*, which is known to *potentially* impair water quality in reservoirs.

On the other hand, within the impacts on biological control there is one case of invasional meltdown. According to the European and Mediterranean Plant Protection Organization (EPPO) (2008) the presence of *Eichornia crassipes* (water hyacinth) – currently in the Ebro Delta – facilitates the survival and spread of the also invasive *Trachemys scripta* (Red-eared Slider), because this turtle feeds on *E. crassipes*. This has been codified as a disruption of biological control, understood as the biological processes that prevent the introduction and establishment of unwanted organisms, such as pests. Instead of eliminating barriers to their entrance, in this case there is an attractor for its establishment.

Table 28

Type of monetary costs associated in the literature to alien species present in Catalan aquatic ecosystems

Source: Own elaboration based on the Exoaqua information system

Status in Catalonia	Species	Damage costs	Control costs
Casual	*Eichhornia crassipes*	•	•
Report of sighting	*Egeria densa*	•	•
	Rana catesbeiana		•
Not established	*Myocastor coypus*		•
	Oxyura jamaicensis		•
Invasive	*Ailanthus altissima*	•	
	Arundo donax		•
	Azolla filiculoides	•	
	Corbicula fluminea	•	
	Cyprinus carpio		•
	Dreissena polymorpha	•	•
	Elodea canadensis	•	
	Myiopsitta monachus	•	
	Neovison vison	•	•
	Pseudorasbora parva		•
Naturalised	*Myriophyllum aquaticum*		•
Uncertain	*Achillea filipendulina*	•	

Given the focus of this dissertation on the water quality issue, it is worth giving a closer look to the species affecting water regulation and purification in Catalonia.

Table 29 shows some of them, sorted according to their effects in water quality, according to the literature, using the dimensions defined by the WFD (physico-chemical, biological and hydro-morphological quality). In this way it is possible to disentangle elements of water quality that are at risk due to the proliferation of the species in Catalonia. Reversely, in case of established species, these are the elements of water quality that can be expected to improve if there is control measures are applied. Note that barely half of these examples are listed as species related to monetary costs (including control costs) in **Table 28**.

Table 29 Water quality and IS impacts in water regulation and purification

Source: Own elaboration

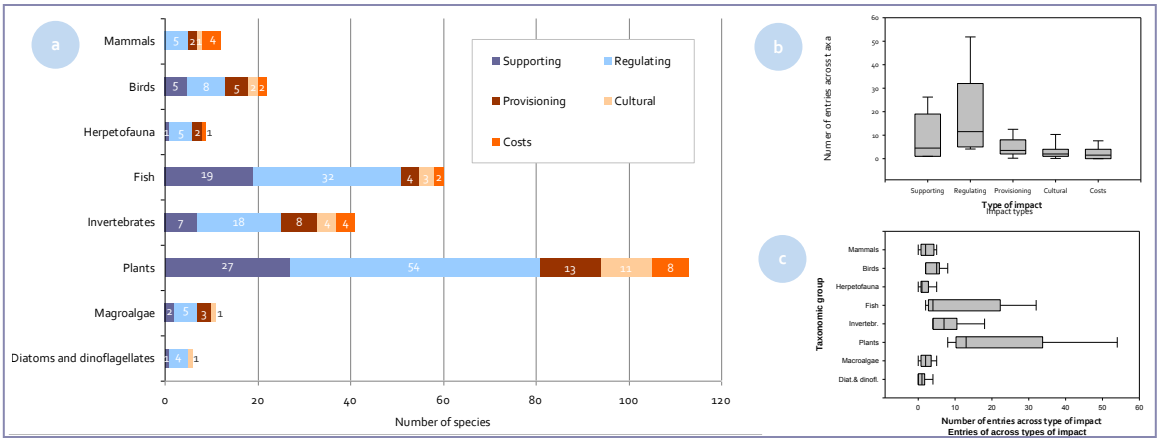
Dimension of water quality	Effect	Examples
Physico-chemical	Changes in water transparency / Increased turbidity	*Alburnus alburnus* (Horppila and Kairesalo, 1992); *Ameiurus melas* (Braig and Johnson, 2003); *Carassius auratus* (Richardson et al., 1995); *Cyprinus carpio* (Barton et al., 2000; Pinto et al., 2005); *Misgurnus anguillicaudatus* (Keller and Lake, 2007); *Rutilus rutilus* (Horppila and Kairesalo, 1992)
	Decrease water temperature	*Egeria densa* (Gettys et al., 2009); *Eichhornia crassipes* (EPPO, 2008)
	Increased nutrient concentration (P, N) and chlorophyll content	*A. alburnus* (Horppila and Kairesalo, 1992); *C. carpio* (Barton et al., 2000; Pinto et al., 2005); *Dreissena polymorpha* (Conroy et al., 2005); *R. rutilus* (Horppila and Kairesalo, 1992)
	Eutrophication	*E. densa* (Gettys et al., 2009); *E. crassipes* (EPPO, 2008)
	Increased Ammonia and NOx (Nitrates and Nitrites) concentration	*D. polymorpha* (Conroy et al., 2005); *M. anguillicaudatus* (Keller and Lake, 2007);
Biological	Changes in phytoplankton & zooplankton communities	*A. melas* (Braig and Johnson, 2003); *C. carpio* (Barton et al., 2000; Pinto et al., 2005); *E. crassipes* (EPPO, 2008)
	Alteration of invertebrates communities	*E. densa* (Gettys et al., 2009)
Hydro-morphological	Changes in the water flow – reduced instream flows	*Arundo donax* (Sanz Elorza et al., 2004); *Elodea Canadensis* (Jukes et al., 2011); *Populus deltoides* (AGIS, 2007); *Salix babylonica* (AGIS, 2007)
	Desestabilisation of sediments	*A. melas* (Braig and Johnson, 2003)

Coming back to the general outlook of impacts, **Fig. 29a** shows the results per taxonomic group and kind of impact, in absolute terms. The side box-plots show the median and the 25th and 75th percentiles of the results across taxa (**29b**) and across type of impact (**29c**), facilitating the analysis of the categories of impact and taxonomic groups, respectively. In order to support a comparative assessment within these categories, the same information has been plotted in percentage, in the two radar charts shown in

Fig. 30 (on the types of impacts, [**30a**]) and (on the taxonomic groups, [**30b**])

Fig. 29 Taxonomic groups of IS in Catalonia, per type of impact

Source: Own elaboration



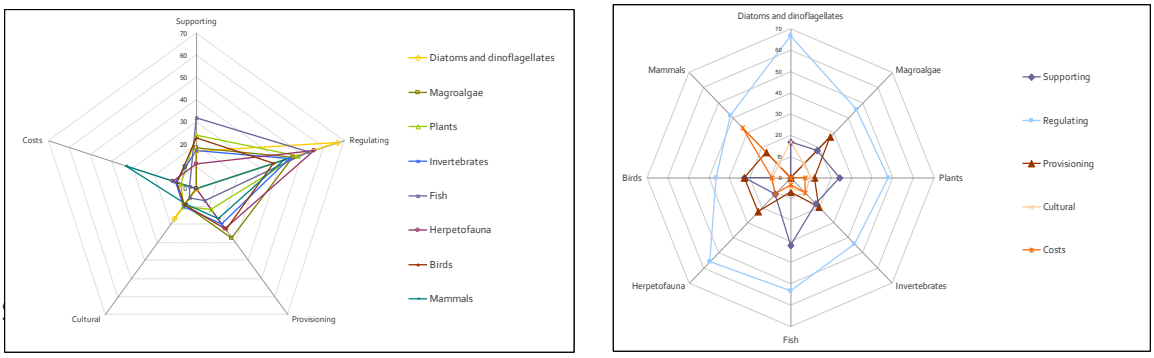
The results point to alien plants dominating in number of impacts, followed by fish and macroinvertebrates. Regulating services such as water regulation, biocontrol and disease regulation (in relation to both animal health and human health) are the main ES affected by these *taxa*. Supporting services, over all those linked to the nutrient cycling and habitat stability, come next.

The number of impacts from species of other *taxa* is visibly lower, although a higher percentage of adverse effects take place on provisioning services, cultural services and through control and management costs. Thus, e.g. ca 22-27 percent of impacts of herpetofauna, birds and macroalgae are related to provisioning services, in comparison to the 12 percent in the case of plants. In the same line, 33 percent of the number of impacts from mammals manifest themselves in form of control costs in relation to ca 10 percent or lower in the other *taxa*.

Leaving aside herpetofauna (with no registries in this category), impacts in cultural services represent 5-10 percent across all taxa, except for Diatoms and dinoflagellaes, peaking to 17 percent. Given to the low numbers of species in this *taxon*, the peak is due to the single registry of the marine dinoflagellate *Alexandrium taylori*, which summer outbreaks provoke recurrent setbacks to the tourism industry (see Giacobbe et al., 2007).

Fig. 30 Radar charts: a) of types of impacts, per taxonomic groups of IS present in Catalonia; b) of taxonomic groups of IS present in Catalonia, per type of impact (scale shows percentages)

Source: Own elaboration



Effects of IS on regulating and supporting ES are socially relevant, as they are eventually related to human wellbeing. However, they may be unnoticeable for the general public. As just shown, in the case of Catalonia, a bulk of the IS impacts in aquatic ecosystems are related to impaired regulating services by plant, fish and invertebrate species. However, people who are not directly involved in river basin conservation and management may care little. Public attention is often focussed on the smaller number of species having a direct effect in provisioning or cultural ecosystem services, or in those involving monetary costs. According to the author experience, species listed in **Table 28** are also among the best known among the Catalan public.

3.3 Current impact of the species in the Ebro River

3.3.1 Effects of *S.glanis* and *D.polymorpha* in the lower section of the Ebro River

Here, the dissertation zooms in on the two aquatic bionvasions described in **Section 1.4**. In order to better understand the impacts of *D.polymorpha* and *S.glanis* on the Ebro, their effects have been classified following the approach presented above. Hence the four categories of ES and monetary costs are used to identify direct and indirect impact of the species.

Table 30 summarizes the effects of *S.glanis* in the river ecosystems services. European catfish may cause ecological impacts due to alterations of the trophic chain and physicochemical modifications of the water contents. Such changes, in turn, would affect the cultural use of the original status of the ecosystems. Anglers opposing the invasive species point out to the loss of traditional fishing practices and the displacement of other introduced species employed for angling (black bass, common carp).

However, presence of the European catfish promotes socio-economic development based on sports angling by non-locals. The income injection seems to be concentrated in a small set of economic agents, many of them external to the region. The benefits include job creation, revenues from tourist services and appreciation of assets (increased land prices, for instance). Also, the expectation of diversifying development options is a non-tangible benefit for this depopulating region sacrificed to external energy production requirements.

Thus, from a purely economic point of view, introduction of the European catfish was locally positive. This may change, to some extent, since there is an emergent view emphasizing the role played by this species in the introduction of other damaging organisms as alien fishes (and their parasites) used as bait and, through them, of the zebra mussel itself.

Table 30 Effects of *S. glanis* on the river ES

Source: Own elaboration

Ecosystem service		Disruption	Available information	Source
Regulating	Water purification and waste treatment	Water quality change	Due to the alterations to the trophic structure of ecological communities, it might affect the water quality of the reservoirs	(Carol Bruguera, 2007)
		Contribution to organic-matter processing	It ingests all kind of organic matter and dead organisms of the river bottom. For this reason, it has been called the 'river sweeper'	Caza y pesca, January 1984.
	Biological control	Competition with other fish species	Noticeable loss of native fish species due to predation	(Doadrio and Aldeguer, 2007)
			Appreciable decrease in catches of other introduced species used for angling (e.g. pike, *Esox lucius*, common carp, and *Cyprinus carpio*)	Gran pesca 08/08/2005, interview to anglers, 8.1.2005
		Trophic alteration	Food decreases for other fish species, including those with sportive interest (black bass, *Micropterus salmoides*)	Gran pesca 08/08/2005; (Carol and García-Berthou, 2010)
		Impacts on endangered birds	Indirect damage to stork broods due to the increase in traffic of anglers	La Malla, 20/06/2005
	Harm regulation	Vectors for the spread of unwanted organisms	Indirect source of introduction of other potentially damaging species, as zebra mussel or the fishes pumpkinseed (*Lepomis gibbosus*) and bleak (*Alburnus alburnus*), used as bait	La Malla, 08/07/2002
		Vector of parasites	Introduction of some parasites has been noted	(Blanc, 1997)
Provisioning	Food	Obtaining of fish biomass	Central European migrants eat the caught fish	Interview P.J. Jimenez, 05.2008
Cultural	Recreation	Sportive angling	Great sportive value	Gran pesca 08/08/2005
		Local development	Provision of services linked to angling practices (meals, accommodation, guiding)	Gran pesca 08/08/2005
		Local and external development	Sales of commodities linked to angling practices (living and manufactured bait, tackle) and promotional merchandise	Interviews, web pages
	Cultural diversity	Loss of traditional fishing practices	Abandonment of traditional fishing practices based on the exploitation of native fishes. Loss of local technological and organizational systems (the '*madrava*')	(Boquera Margalef and Quiroga Raimundez, 2001)

The scope of ecological and economic impacts of the zebra mussel and its character of a 'global invader' makes it one of the most studied species in the world , with large production of scientific literature on the species as referred in the National Aquatic Species Clearinghouse (http://aquaticinvaders.org). This bibliographic database has a large section for *Dreissena* spp, very much focussed on *D.polymorpha*, which returns up 91 matches within the search parameter 'monitoring', and 79 within 'infrastructures impact', only to mention two items.

As displayed in **Table 31,** there is an evidence of ecological impacts of zebra mussel in the Ebro through the alternation of the trophic chain and the change in substrates. Together with other more influential changes in the physicochemical quality of the water, like lower dissolved nutrients (Ibáñez et al., 2008), zebra mussel may cause a positive effect on water transparency and reportedly to the increase of macrophytes. Its abundance also triggers processes of cyanobacteria proliferation.

Among the ecological impacts, the most commonly known are the damage to the pearl mussel (*Margaritifera auricularia*) and to another native bivalves. This has been proved, for instance in the colonised area of the Urrúnaga reservoir, also in the Ebro river but far from the study area in this dissertation, where the colonies of *Anodonta anatina* are suffering negative impacts from *D.polymorpha* to the extent that their survival is threatened (Madeira García et al., 2012).

However, the interviewed stakeholders indicate that public concern about zebra mussel arose primarily from the evidences of economic damage to infrastructures. The impaired infrastructures encompassed power generation, irrigation systems and municipal water supply in several villages along the Ebro River. In 2002, the energy sector suffered damages in the grills of the Riba-roja dam and the cooling system of Ascó nuclear power plants (NPP), which implied both electricity production losses and large replacement and treatment costs. Being greatly impaired by the invasion, the electrical company developed an early research program on the invasion and thus became the main scientific advisor to the other sectors (e.g. Palau and Cía, 2006). Another nuclear power plant, Garoña, next to the Sobrón reservoir at the headwaters of the Ebro, also applyed control measures against the zebra mussel after suffering from diverse problems in the cooling system (Diario de Burgos, 15/12/07).

Impacts in the municipal water supply appeared soon. In 2002, Faió, a small village relocated in the Aragonese shores of the Riba-roja reservoir, had to completely replace the intake facilities, spending about EUR 490,000, 80 percent paid by the regional government (www.fayon.es). Other impacted municipalities in Aragon are Biota, Ciprana, Gallur, Grisén, El Burgo, Fabara y Nonaspe (El Periódico de Aragón, 10/04/08, El Heraldo, 27/02/08). So far, the largest damage tracked in an urban area has been Logroño in La Rioja that suffered from the collapse of the pipes for irrigation of its green areas in 2007.

The reservoirs already invaded were the intake points of large irrigation infrastructures, so the agricultural sector was thereafter also damaged. When interviewed, the representatives of irrigation societies recognized the presence of the zebra mussel in their infrastructures. Commonly, they regard the bivalve as a nuisance rather than a source of serious damage. However, in the low section of the Ebro River, the irrigation societies of Benissanet and Ascó reported costs for the replacement of grills, pumping systems and pipes. In the Mequinensa and Riba-roja reservoirs, irrigation societies from Fabara, Nonaspe and Mequinensa reported damages and asked for financial support from the regional government (El Periódico de Aragón, 10/04/08). An increasing number of irrigation societies upstream from the study area also reported impacts on their infrastructures in Navarra (several irrigation societies from Tudela, Cintruénigo and Mendavia) and in Álava (irrigation societies from Baños de Ebro, Oyón and Lapuebla de Labarca) (Diario de Navarra, 07/03/08, Diario de Navarra, 05/07/08).

In addition to the direct impacts caused by the species, the response to the invasion implied considerable expenses in research and control costs by different administrations (CHE, ACA, Instituto Aragonés del Agua and the environmental and agriculture authorities of different regions). Besides

such costs, the responses to the invasion have led to navigation restrictions, affecting the leisure value of the area and causing conflicts between the authorities and the recreational users of the river (Dittmer, 2008).

Table 31 Effects of *D. polymorpha* on the river ES and impacts on human-made infrastructure

Note: (1) Type of impact: D – direct (of the invasive species), I – indirect (stemming from the management response)

Source: Own elaboration

Ecosystem service		Change	Available information	Type[1]	Source
Supporting	Nutrient cycling/ PP/ habitat stability	Trophic alteration	Zebra mussel filters phytoplankton from the water (up to 1l/day each)	D	(Freixe and Jiménez Ruiz, 2002)
Regulating	Water purification	Water transparency	Contribution to increased water transparency due to the filtering capacity	D	(Freixe and Jiménez Ruiz, 2002)
	Soil formation? (supporting)	Changes in substrate	Changes in substrates due to the accumulation of shell deposits	D	(Masip and Rofes, 2003)
	Biological control	Increased presence of macrophytes	Contribution to the increase of the presence of macrophytes due to the water transparency [contested]	D	(Freixe and Jiménez Ruiz, 2002)
	Harm regulation	Vectors for parasites and diseases	Appearance of cyanobacteria (*Phormidium*) related to the activity of zebra mussel, the lack of flow and high temperature	D	(Freixe and Jiménez Ruiz, 2002)
			Likely vector of the introduction of the parasite *Phyllodistomum folium*	D	(Palau and Cía, 2006)
Provisioning	Genetic resources	Competition with local species	Increased pressure to the endangered unionids *Margaritifera* sp.; *Anodonta cygnea*; *Unio elongatulus* , *Psilunio littoralis*	D	(Freixe and Jiménez Ruiz, 2002)
Cultural	Recreation	Loss of navigation / angling services	Cutting of fishing lines	D	Interviews to anglers and marina managers
			Damage in boats and other equipment	D	
			Use of antifouling paintings in boats	I	
			Construction of several cleaning stations for boats	I	
			Increase requirements to navigation authorisation, boat cleaning rate fees; restrictions to boat mobility	I	
Impacts on human made capital (Infrastructure)	Damage / treatment on infrastructures	Effect in facilities for human supply	Loss and replacement of suction pump and pipes	D	Interviews to infrastructure managers (2005-2010)
			Installation of filtering systems	D	
			Cleaning chemical treatments (chlorine and hydrogen peroxide)	D	
		Irrigation systems	Change of damaged grilles and pipes	D	
			Chemical treatment of pipes and regulation water tanks	I	
		Effects in hydroelectrical power plant	Loss and replacement of grills	D	
			Use of antifouling covers	I	
		Effects in the cooling system of Ascó NPP	Cleaning activities in the tanks: increase of the water temperature by closed system operation	I	(Asociación Nuclear Ascó –Vandellós, 2003)
	Production loss	Underemployed infrastructures	Loss of hydro-electrical and nuclear energy during treatment	I	Interviews to infrastructure managers

3.3.2 Monetary estimates of impacts of the zebra mussel invasion in the Ebro

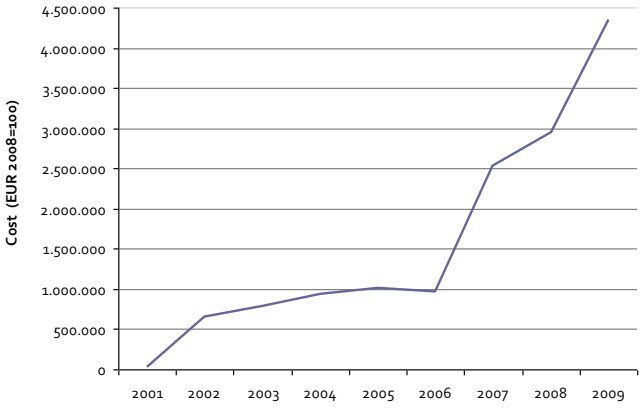
The CHE commissioned a monetary valuation of zebra mussel costs in the Ebro and a subsequent update of the estimates (Pérez y Pérez and Chica Moreu, 2010, 2006). The first calculation estimated a mix of damage and control costs of around EUR 2.6 m between 2001 and 2005, mostly taking place in the region originally invaded. The update of the study, for the whole basin, pointed out a sharp increase of the costs to EUR 11.6 m for the period 2005-2009 (**Fig. 31**).

Fig. 31

Costs of the invasion of *D. polymorpha* in the Ebro River (whole basin)

Note: Data for the period 2001-2004, for the low Ebro basin only. Original data, in current terms, has been deflacted (2008=100).

Source: Cost data from Pérez y Pérez and Chica Moreu (2010, 2006) ; deflactor from the Instituto Nacional de Estadística y Banco de España



In order to better grasp the kinds of cost born by the regional stakeholders and governmental departments in charge of the invasion, a supplementary survey was run in the study area between 2007-2008, financed by the Spanish Ministry of the Environment and coordinated by the author of this dissertation. The objective of the survey was to assess the order of magnitude of impacts of the zebra mussel in the low section of the Ebro River (downriver from the Mequinensa reservoir), with particular interest in the temporal evolution of the monetary costs. The results of the cost estimates, summarised here, were reported in Dittmer and Rodriguez-Labajos (2009) and Rodriguez-Labajos and Dittmer (2009). The corresponding questionnaires are presented in **Annex II**.

As an initial framing of the survey, the range of potential socioeconomic impacts of *D.polymporpha* was assessed through a literature review. A stakeholder analysis was then undertaken, defining sectors according to their use of the environmental services affected by the species, or their role in the management of the invasion. Beside the different types of cost born, the survey also enquired about the perception of the relevance of such impacts. The main sectors considered were regional authorities, municipalities, hydroelectric companies and other industries, irrigation communities and fluvial tourism establishments. The primary method of comprehensive data collection was sector-specific mail and telephone surveys directed at all the potentially affected entities, with 81 respondents (**Table 32)**. The questionnaires were designed and piloted based on in-depth interviews with representatives of each sector. Additional information on impacts in the study area was obtained through a review of official documents and press releases. That was particularly useful in the case of the industry sector.

Table 32

Number of survey respondents, per sector

Source: Rodriguez-Labajos and Dittmer, 2009

Sector	Structured interviews	Mail questionnaire	Phone questionnaire
Regional authorities	4	4	-
Town councils (N=32)	-	18	6
Irrigation societies (N=41)	Unspecified	15	20
Tourism (marinas) (N=20)	10	8	6
Industries	1	-	4

Results are shown in

Table 33 and plotted in **Fig. 32-33**. The series show an initial increase in cost during the whole period, which declined slightly after the stabilisation of the invasion. However, after 2006 the evidence of the spread of the species to different points of the basin mobilised resources for control. This had the effect of increasing control costs also in the area of the original invasion. It must be clarified though that there is a part of the expensed applied by the national and regional authorities for the period 2006-2008 that had effects far beyond the study area (e.g. information campaigns).Their amounts have been fully included here, as it has not been possible to discriminate their geographic span.

Table 33 Cost estimates of the invasion of *D.polymorpha* in the Ebro River (study area) (EUR, 2008=100)

Note (1) Including subventions to other sectors; (2) Excluding subventions; (3) It includes expenses for zebra mussel control with benefits outside the study area.

Source: Own elaboration, based on Rodriguez-Labajos and Dittmer, 2009

Sector	2001	2002	2003	2004	2005	2006	2007	2008
National / regional authorities [1]	15,204	51,109	152,504	322,446	165,311	194,146 [3]	709,143 [3]	958,387 [3]
Local councils [2]	5,068	8,503	8,233	25,396	13,993	15,078	6,320	9,200
Industries	7,602	594,312	610,613	617,936	453,085	425,306	414,014	406,172
Irrigation societies [2]	4,089	13,638	13,110	19,588	30,490	33,500	33,118	58,168
Tourism (marinas) [2]	-	-	61,832	9,911	9,546	9,215	8,970	8,800
TOTAL	31,963	667,562	846,292	995,277	672,426	677,245	1,171,566	1,440,727

In absolute terms, the biggest costs were initially born by the industry, basically by the energy sector, with orders of magnitude ca EUR 400,000-600,000 a year after the evidence of massive invasion. The yearly cost has declined after the application of adaptation procedures in order to avoid damages to infrastructure (recirculation of warm water in the nuclear power plant, cleaning of grills in the hydropower plants). However, they entail periodic losses in energy production. These costs are considered as important by the respondents.

The magnitude of the economic cost in the agriculture and tourism sectors is remarkably smaller, lower than EUR 50,000 a year. However, due to the narrow mark-ups in agriculture, one third of the irrigation societies consider that such impacts are important. Thirty percent of the municipalities supplied from intakes in the Ebro River state that they have to spend in control costs of relevance at least moderate, generally subsidised by the regional administration.

Actors related to navigation and angling business seem to have suffered the bigger indirect impacts, i.e. stemming from the management measures to prevent the invasion process to new areas. Such impacts are a result of administrative requirements and several restrictions to boats' mobility.

Fig. 32 Total cost of the invasion (study area)

Source: Own elaboration

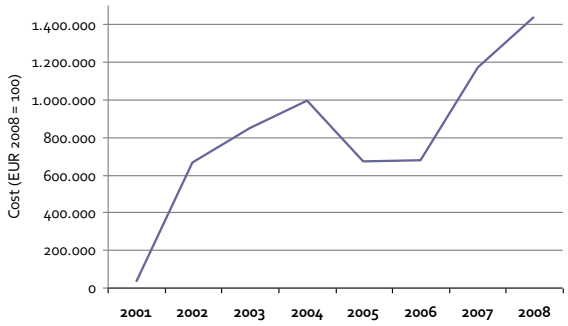
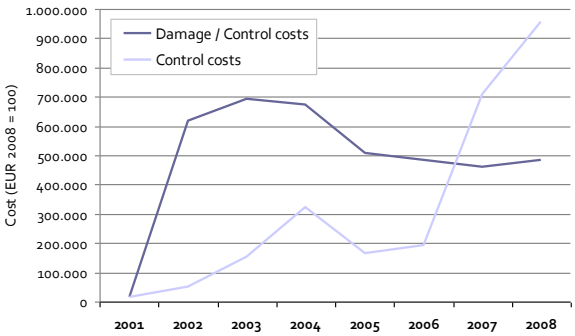


Fig. 33 Damage and control costs (study area)

Source: Own elaboration

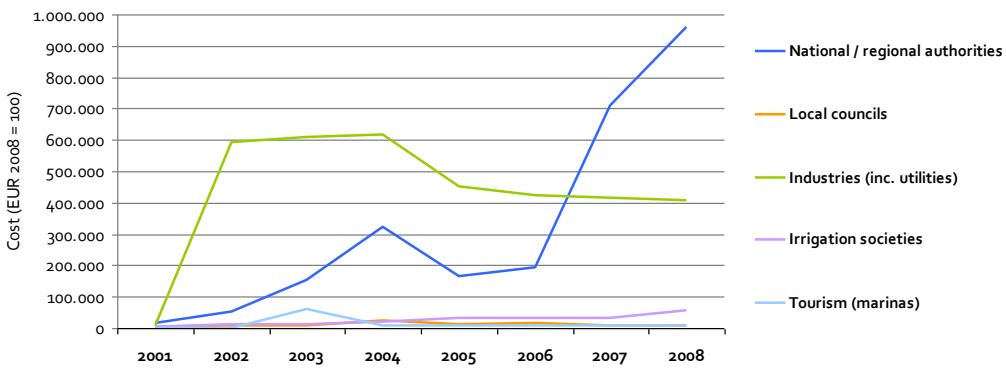


To a great extent, the evolution of the costs for the administrations explains the different patterns of the damage and control costs. The available information did not allow to discriminate both costs in many cases. In certain situations, such as the replacement of damaged equipment with adapted devices, both types of costs are expressed by the same expense. Still, separating the purely control cost (attributable to the expenses of the national and regional authorities), from the mix of damage and control cost in the other sectors, points at two processes a) damage cost tend to decline after the period of massive invasion, and b) by the end of the assessed period, control costs largely exceed damage costs. This had probably the effect of reducing further damages both in the study area – since control cost were often focussed on preventing spread – and to alleviate or delay damages in other areas.

Fig. 34

Cost of the invasion, per sectors (study area)

Source: Own elaboration



3.4 Potential impact of the zebra mussel in a non-affected area

The purpose of this section is to assess the possible cost of the zebra mussel invasion in an area subjected to the same driving forces but currently not affected by the invasion.

3.4.1 A methodology for the ex-ante calculation of impacts

The objective is not the calculation of extremely accurate estimates, but rather proposing and testing a methodology that enables the assessment of this and other potentially invasible areas in a fast but reliable way. The steps of this methodological proposal are described next.

Step 1. Catalogue of all plausible kinds of impacts in the study area. Besides the ample literature on the impacts of *D. polymorpha* worldwide, it is appropriate to use the information available for the closest context to create a check-list for the identification of impacts.

Step 2. Specification of how each one of the impacts would take place in the assessed site. This step includes three different elements:

a) the scrutiny of possible performances of the impact in the assessed site, given the known uses of the river,

b) identification of the sector that would be bearing this impact; and

c) Specification of possible management measures to tackle the impact, if any.

Step 3. Indication of an order of magnitude for the impact, in terms of the possible associated cost. As there is uncertainty on the specific conditions that may prevail, the precise value of the costs cannot be known *ex ante*. However, the knowledge gained from the analysis of the closest case (e.g. the Ebro) is a good pointer of the range of values involved for different kinds of impacts.

Step 4. Development of the management scenarios. This point is extensively discussed in **Chapter 4**.

Step 5. Characterisation of the intensity of the each specific impact under different management scenarios, and along the different moment of the invasion process (from the pre-invasion context to the permanent post-invasion situation). Intensity can be expressed, for instance, in a scale of 0 to 10, where 10 is the highest intensity.

Step 6. Considering the intensity of the impact with its magnitude, for each of the scenarios, and analysis of results. In a more sophisticated application of this methodology, the intensity can be related with the results of a biological model explaining the evolution of the species populations in face of the management scenario. This possibility is not tested here.

3.4.2. Testing of the methodology: the reservoirs of the Ter River

Step 1. For the non-invaded areas in the Iberian Peninsula, the obvious reference is the Ebro River. In particular, the effects in the area initially invaded help to recognise the likely temporal evolution. **Table 34** summarises the information about impacts based on the knowledge of effects of the

invasion on that area. Here the impacts have been classified as either damage costs or control costs, specifying the distinction between direct and indirect costs explained in **Section 3.1**.

Table 34 Catalogue of impacts caused by *D. polymorpha* in Catalan basins

Source: Own elaboration

Type of impact		Direct from the invasion	Indirect from the management
Damage	Impacts on infrastructure and equipment (decreased useful life, increase maintenance costs, in €)	Covering of solid surfaces (walls, bottoms) in infrastructure for water distribution (canals, pipes) Covering of solid surfaces (walls, bottoms) in water storing infrastructures(water tanks, pools, weirs and dams, settling ponds) Clogging of water management devices (e.g. grills, inspection chambers, sluicegates, water traps, filters, pumping devices, sprinklers, pipes, hydrant, cooling circuits) Decrease flow capacity of pipes due to partial clogging (increased friction) Damage to other equipments and materials (e.g. electronic monitoring equipment)	-
	Production loss due to damaged infrastructures (production value in physical units or €; changes in profitability)	Electric power production Agriculture production Supplied population Direct loss on the tourism sector	Effects on electric power production from run-of-the-river power plants, due to deliberate changes in water flows Losses in the tourism sector from access restrictions
	Damage to ecosystem services related to environmental quality (physical units or qualitative)	Perception of environmental quality loss (including impacts in biodiversity) Water availability (need of alternative sources of supply)	Impacts in water quality due to the implemented treatments (thermal, chemical) Perception of decreased recreational / aesthetic value of the water body due to access restrictions
Control	Installation of equipment and implementation of treatments for preventing introduction, establishment and impacts of zebra mussel (in EUR)	Replacement of damaged equipments with improved preventive properties	Filters Use of anti-fouling covers (e.g. paints) Disinfection equipments Changes in the drinking water treatments Treatments in irrigation systems
	Additional costs for management (in EUR)	Costs of monitoring of the invasion Costs of research Cost of communication	Additional costs due to manoeuvres on the water flow (reservoir draining, sluicegates management) Additional costs for the operation of the disinfection systems (e.g. certification) Expenses for mitigation, subventions for the installation of equipment Management and transition costs (e.g. *ad hoc* MoU among authorities in charge and related stakeholders)

Step 2 – Step 5. An example of implementation of the proposed scheme is shown in **Table 35** (just for the first item in **Table 34**). The complete specification of each one of the items is included as **Annex III**.

Each one of the items listed in **Table 34** is examined according to the knowledge about the non-invaded area. Although this methodology aims at providing quick assessments of impacts, it does not avoid requiring good knowledge of the study area: the more detailed the information, the more precise the calculation of costs. In particular, certain level of knowledge about the technicalities about water management infrastructures and practices in the area is needed. In this case, this has been obtained through a number of talks with water managers and stakeholders and visits to the area during the period 2006-2010. Obviously the process can be expedited by identifying and interviewing key informants.

In the current assessment, the sectors potentially bearing costs needed in **Step 2** are urban water supply (UWS); hydropower production (HPP), regional authorities (AUT), navigation-related activities (NAV); angling (ANG), and irrigation systems (IRR). Note that here the term 'order of magnitude' mentioned in **Step 3** is used in a non-decimal system, for which three levels of annual costs have been defined: (1) relatively low costs ranging between EUR 3,000-8,000; (2) moderate costs ranging between EUR 20,000-50,000; (3) relatively high costs ranging between EUR 150,000-400,000. These ranges have been obtained examining data from the Ebro River case.

Scenarios defined in **Section 4.3.4** are used here for the purpose of the exercise in the Ter River. Hence, three possible scenarios are distinguished: 'Do nothing', 'Mitigation', and 'Adaptation'. For each scenario, there are four moments of the invasion are considered: the pre-invasion context (Pr); the first alerts of the invasion (PrA); the post-invasions moment, when there is evidence of massive impact (Ps_1); the permanent post-invasion situation (Ps_t).

Table 35 Example of implementation of the proposed methodology for the assessment of impacts in the non-invaded area

Note: **Sectors:** Urban water supply (UWS); hydropower production (HPP), regional authorities (AUT), navigation-related activities (NAV); angling (ANG), and irrigation systems (IRR); **Order of magnitude of annual costs:** (1) EUR 3000-8000; (2) EUR 20,000-50,000; (3) EUR 150,000-400,000; **Moments of the invasion:** pre-invasion (Pr); first alerts of the invasion (PrA); post-invasion, first moment (Ps_1); post invasion, permanent (Ps_t).

Source: Own elaboration

Effect: *"Covering of solid surfaces (walls, bottoms) in infrastructure for water distribution (canals, pipes)"*	Sector	Mgmt	Order of magnitude	Intensity											
				No action				Adaptation				Mitigation			
				Pr	PrA	Ps_1	Ps_t	Pr	PrA	Ps_1	Ps_t	Pr	PrA	Ps_1	Ps_t
Covering the surface of the aqueduct from Pasteral reservoir to the Ter ETAP	UWS	Pre-treatment at the intake of the aqueduct	2	0	0	10	8	0	0	5	3	0	0	3	0
Covering the pipe from the ETAP to the Trinitat distribution station	UWS	Treatment in the Ter ETAP	2	0	0	7	5	0	0	3	1	0	0	0	0
Covering the canal from the Pasteral II to the Montoliu ETAP	UWS	Facilities for pre-treatment in Pasteral II	3	0	0	10	8	0	0	10	3	0	0	3	0
Covering irrigation canals	IRR	Facilities for filtering the diverted water flow	2	0	0	10	8	0	0	10	3	0	0	3	0

Step 6. The results of implementing this procedure for the case of the Ter River are shown in **Table 36** and **Fig. 35**. As indicated above, these are obtained by direct weighting of the intensity of the impact with the magnitude of the cost (at the extreme values of the range).

Table 36 Estimates of annual costs (EUR) in the Ter River (non-invaded area)

Source: Own elaboration

Scenario	Pre-Invasión		Pre-alert		Post-invasion (immediate)		Post-invasion persistent	
	Min	Max	Min	Max	Min	Max	Min	Max
No action	0	0	0	0	1.653.400	4.388.400	1.318.800	3.500.800
Mitigation	75.800	193.800	77.600	198.600	1.780.300	4.711.800	274.400	713.400
Adaptation	705.500	1.873.000	92.800	234.800	182.900	467.400	91.700	230.200

In rough outlines, the results for each scenario can be explained as follows. The '*No action*' scenario does not entail costs in the pre-invasion and pre-alert phases, as none of the stakeholders invests in preventing the introduction of the species or adapting their activities to avoid future damages. As long as the invasion does not manifest itself, this is the scenario with the lowest cost at these two phases. However, the situation changes dramatically once this happens. The costs peak in the immediate post-invasion phase. Still, the actors do not perform any management action and the high level of costs persists over time, linked to the evolution of the species populations. If no measure is put into practice, what can be expected is a certain stabilisation of the population (and therefore, a certain reduction of the intensity), but not its disappearance. As a result, the post-invasion persistent costs are kept at high levels in this scenario. Population cycles will be reflected in future

As explained in detail in **Section 4.3.4,** the '*Mitigation*' scenario focuses on all possible actions tending to avoid the next undesired event. This, in the pre-invasion phase, is the invasion itself. The scenario entails then all kinds of investments in prevention and monitoring, but no investments in reducing future damages, which explains a remarkably lower cost in this phase than the '*Adaptation*' scenario. As a result, if the invasion eventually proliferates in the area, the impacts reach the highest possible level. At the same time, facing the fact that the undesired event now is the damage by the species, the immediate post-invasion phase is the moment when investments are done to mitigate damages. For this reason, the costs in this phase are even higher than the 'No action' scenario. However, the investments yield results when lesser persistent costs are born in the long term.

Meanwhile, the '*Adaptation*' scenario considers actions tending to reduce the impact of the invasion rather than its occurrence. This means that costly investments in infrastructure are done in the pre-invasion context in view of a process that is deemed as unavoidable. Monitoring costs are also born, but basically with the purpose of rapid response after early detection. The activation of response protocols to mitigate damages explains the costs during the pre-alert phase. The outcome of all the investments is the lowest impact level both in the immediate and in the persistent post-invasion contexts (that could be around one third of the costs in the 'Mitigation' scenario and less than one tenth of the 'Do nothing' scenario).

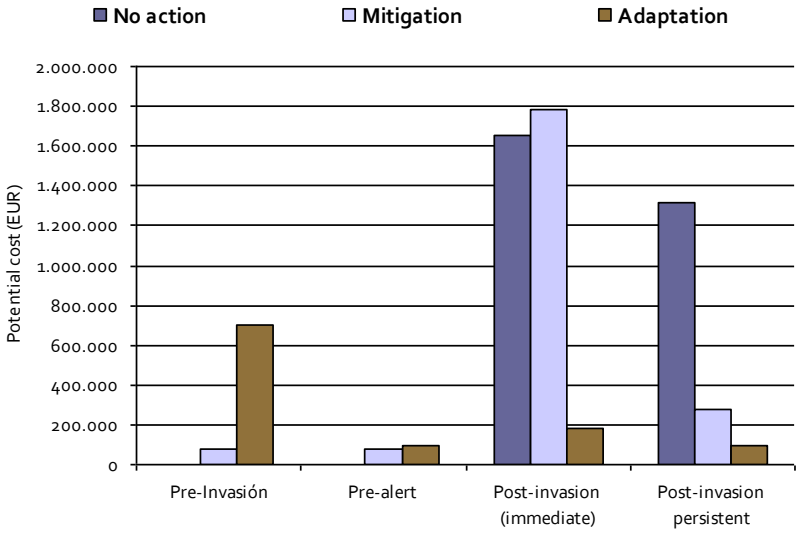
Fig. 35 illustrates the argumentation made, facilitating the comparison of each invasion phase for the three scenarios. Something that cannot be forgotten is that the option for each one of the management strategies modifies the duration and the likelihood of each one of the phases. The 'No action' scenario may accelerate the pre-alert phase, same than the 'Mitigation' scenario is likely to delay it. Therefore, the outcomes within each phase do not belong to the same moment in time. If a comparable expected value (in the sense of a mathematical expectation) is needed, the estimates of

cost for each scenario should be weighted with the probabilities of occurrence of each phase along a time line. Rather than this level of detail, that may require further calculations and resources, the purpose here is to provide rough estimates of costs that can support management options. Tactically speaking, the method provides facial composites of suspect, rather than high definition pictures of the corpse.

Fig. 35

Estimates of possible annual costs (EUR) in the Ter River (lower range)

Source: Own elaboration



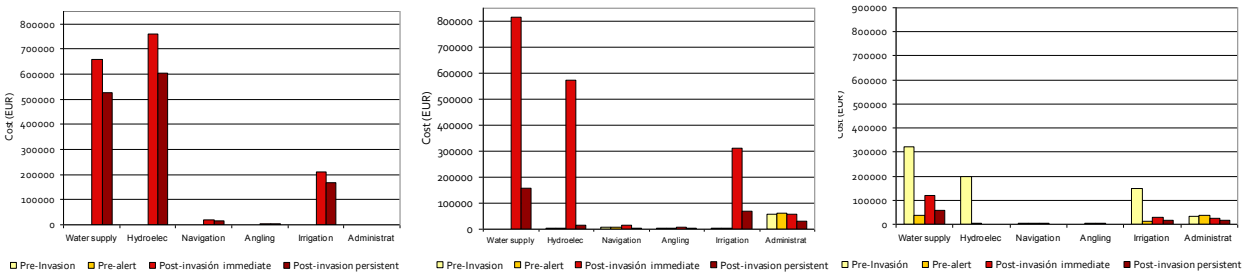
This method also allows comparing the distribution of costs between the main types of actors involved, along the invasion process.

Fig. 36 shows the result of this calculation, for each one of the scenarios.

The hydroelectric sector and water supply managers would be impacted sectors in all scenarios, followed by sector involved in irrigation. In the 'No action' scenario, high damage cost would be suffered during the post invasion phase, both in the short term and also persistently. In the case of the 'Mitigation' scenario, the administration would be bearing most of the pre-invasion costs. In the post-invasion phase, damage costs would be high immediately after the invasion, but due to the measures taken to prevent further damage, damage cost would be reduced in the persistent post-invasion stage. The 'Adaptation scenario' would entail high control costs by those actors more prone to suffer damage cost already during the pre-invasion phase. As a result, the damage costs in the post-invasion phase get considerably reduced in relation to the other scenarios.

Fig. 36 Estimates of possible distribution of annual costs (EUR) between main actors in the Ter River (lower range): a) No action; b) Mitigation; c) Adaptation

Source: Own elaboration



3.5 Management-oriented considerations about impacts

3.5.1 Fundamental attributes of IAS impacts

After analysing impacts of AIS at different scales (EU, Catalonia, the local scale in pre-invasion and post-invasion context), four main attributes are deemed as the most challenging ones for water management:

- *IAS impacts on water quality are multi-dimensional*. AIS in aquatic ecosystems cause impacts in all ecosystem services categories, being thus an important driver of change in water quality. The range of impacts differs among species. Some species affect all dimensions of ecosystem services, while others are characterised by specific impacts, perceived as highly damaging. The species cause intertwined ecological and economic effects, affecting both the biological quality of water and socio-economic activities reliant on such quality. Those species with highest potential of impacting water quality (e.g. fish as *Ameiurus melas* or *Carassius auratus*) are not necessarily those associated with monetary costs (e.g. *Neovison vison*), which are more conspicuous for the general public. In Catalonia species causing monetary costs are only a small part of the species causing impacts, and a tiny part of the scope of AS present in aquatic environments.

- *IAS are ambivalent*. AIS can be the source of simultaneous positive and negative considerations. On the one hand both their role in the ecosystem and the social perception about them cannot be always be qualified negative. In the socioeconomic dimension, this is particularly apparent for those fish species deliverately release for angling purposes, regarded as a price for some, and as a scourge for some others. On the other hand, the existence of facilitative interactions between AS, a phenomenon that is in the origin of the so-called invasional meltdown, can be regarded as a possible source of ambivalence. Even if there is not a negative judgement about a given effect of a given AIS *per se*, this can change whenever there is evidence that its presence contributes to further (and undeniably damaging) invasions. Therefore, AIS ambivalence is explained by contradictory social perceptions, but it is eventually rooted in the functional role of the species. While the first characteristic could keep the discussion clung to the sphere of ethics, the second one gives the possibility to bring it back to the arena of ecologically underpinned assessment.

- *IAS impacts are often unknown*. The invasive species impacts are not always well-known. A good example is the ecological impact of *S.glani*s. Many signs indicate that its introduction has intensely modified the local ecosystems. However, nowadays there are many aspects of the ecology of this fish that are poorly understood. For this reason there is reluctance among scientists to accept any categorical statement about its impacts and especially about its effects on native biota, maybe fearing to be qualified as providers of anecdotal, journalistic information. Is this a case of 'manufacturing of uncertainty'? The precautionary approach calls for caution. However, the scientific reluctance to take a stand on the effects of *S. glani*s on biodiversity fits well with the agendas of those actors highlighting the tangible economic effects rather than the uncertain negative impacts of the species. In the case of the zebra mussel, the massive evidence of negative economic impact has shadowed the debate about how its ecological hazards (sometimes also put into question) are understood and dealt with. As indicated above, ca 75 percent of the species already present in the Catalan aquatic ecosystems lack a characterisation of impact, a situation that may not be as different at the European level. Thus,

knowledge gaps about the biology and ecology of the species, and about the interaction with different recipient ecosystems made the assessment of impacts a challenging task. Moreover, as highlighted by Strayer (2010), interaction between IAS impacts and other kinds of stressors in freshwater ecosystems is poorly studied.

Besides the caution imposed by the biophysical dimension, there are two other aspects of uncertainty to keep in mind, over all when talking about impacts of future or on-going invasion process. On the one hand, there is the time dimension involved, as often information about AS impacts is required at early stages of the invasion process, or even before it has taken place. On the other hand, the occurrence of certain impacts depends on social choices.

- *IAS impacts are management-dependent*. Besides the damage directly caused by the species, impacts also depend on the way how the invasion is tackled. For instance, zebra mussel clogging irrigation pipelines can be avoided though releasing chemicals such as chlorine. However, this response may trigger new impacts as now the crops are exposed to higher doses of this compound. Therefore, reflexive complexity must be also included in the assessment of AS impacts. This comprises two different aspects. First, the strategy adopted distributes differently the impacts over time. An early reaction may prevent considerable damage costs in the long run, but it is costly itself. Second, the objective of the management can drift between two extreme 'mitigation' or 'adaptation' approaches, with different degrees of implementation according to resource availability. The choice between strategies is not neutral and it manifests itself both in the type of emerging impacts, their possible magnitude and the moment of the invasion process when they take place. The calculation of some of the possible monetary impacts in the Ter River presented above serves as an illustration of this.

3.5.2 Implications for management-oriented assessment

From the above, three aspects should be taken into account when **framing the objectives of management-oriented assessmen**t of invasion process. First, a multidimensional view of IS impacts can foster their management. An accurate but exceedingly focussed assessment may mislead action only to specific facets, disregarding alternative views of the problem at hand. Second, the differentiation between direct and indirect impacts (i.e. those caused by invasive species on ecosystem functions and human well-being vs those derived from the implementation of response actions) matters. In this respect, a proper distinction of these kinds of impacts allows evaluating the consequences of AS along the stages of the invasion process and also the social agents linked to them, informing decision-making and supporting the implementation of management strategies. Third, in order to gauge the effort needed to estimate impacts, fitness for purpose should be emphasized. Monetary calculations are often introduced as a way to express AS impacts. However, the technicalities of a monetary assessment make a timely outcome very difficult. Then, when available, how is the result employed? In the experience of the zebra mussel invasion in Spain, the production of monetary costs has been used as an awareness mechanism, often mentioned in communication, but not used as a signal for triggering cost-efficient management measures. Is it really necessary to have monetary estimation of costs for a good AS management?

Based on these considerations, the next paragraphs offer remarks about the **methodological approaches** to be used for management-oriented assessment.

- *Uses and limits of monetary assessment of impacts*

Traditional economic assessment of impacts can face some aspects of the problem. Monetary estimations provide an easy-to-understand figure that can be used to increase awareness about the seriousness of the invasion issue. However, consistently with its theoretical basis, monetary assessments will analyze and give signals only about those elements of the problem that can be translated to economic values. It is likely that this approach tends to focus the response on preventing impact to human activities (fundamentally the economic ones). Those aspects that the market (or a fictitious market) cannot reveal – as some elements of biodiversity loss– will not be regarded as a problem. The aggregation of different kinds of costs is also an obstacle for the use of the results in management, since it conceals useful information to stakeholders and policy makers. In particular, the aggregations hides trade-offs between different management options. The distinction between direct and indirect impacts should be made explicit to identify when a certain management option diminishes one impact and at the same time promotes another.

These limitations put into question the suitability of monetary valuation as an evaluation tool for policy advice, indicating the need for more comprehensive studies. Incidentally, a comparison between monetary assessment and multi-criteria evaluation shows the latter to be as a more helpful technique for addressing the uncertainties involved in public decisions about biological invasions (Rauschmayer, 2003). In this regard, studies have proved the utility of cost-effective analyses and multi-criteria evaluation as assessment method of biological invasions (Groote et al., 2003; Maguire, 2004; Monterroso et al., 2010). As shown in the following **Chapter 4**, there is also a set of methods, such as risk assessment and scenario development, to explicitly address uncertainty in the policy-oriented assessment of AS. They all include options for displaying and structuring information on impacts in a comprehensive way.

- *The central role of ecosystem services and their values*

The integrative analysis of impacts –as in the ecosystem services framework- can help to prioritize strategic policies and actions, as well as to identify the potential stakeholders involved in the invasion process (as driving forces, affected or as the ones implementing or being influenced by the responses).

In this chapter, the ES scheme has been used to classify and analyse impacts of AS at three scales. In this way, the utility of the scheme has been proved for several purposes:

- As we already asserted in Binimelis et al. (2007a), the use of the ES categories helps to illustrate, at different scales, the human dependence on ecosystem functioning and the impacts that invasive species cause on it. Ordering information in an easily understandable framework facilitates the links between ecosystem change and human interests. In analytical terms, it also discloses information gaps; since it reveals whether the information about impacts is available or not and it evidences that some impacts are better validated though scientific research than others. This is important both for decision-making and the design of further applied research.

- To appreciate that the nature of invasive species' disruption of ES is complex. While organizing the different impacts depicts a complete picture of the impacts, it is difficult to isolate an

effect that is not connected to various ES. This is an echo of the inherent complexity of the aquatic ecosystem functioning, which is far from being completely understood.

- To consider the potential and limits of economic valuation of ES. Some impacts on ES can be assessed with cost-based methods (e.g. opportunity cost or avoided/damage cost). This is an approximation of the monetary effects of the invaders when related to market-tradable goods and services. For instance, presence of zebra mussel in the Ebro has damaged infrastructures and impaired cultural services related to the recreational value of the area. Such impacts may be object of economic valuation attempts that are likely to support decision-making processes based on cost-benefit analysis. However, impacts of the species on regulating services through change in substrates or in supporting services through trophic alteration are difficult to value in monetary terms. Scarcity of data is not a reason to avoid valuing, but the intrinsic nature of processes that are not a part of the marketed goods are. This should not be solved by the imposition of the market rules to the deliberation on the impacts. Rather it is advisable to accept that some impacts that cannot be valued in monetary terms and the social actors involved have to acknowledge other languages of valuation.

Even in those cases when the valuation is simple, there is another aspect that challenges the analytical division between damage and control costs. It is common than the same expense is related to both. For instance, damaged devices in the irrigation sector are commonly substituted by mechanisms preventing the zebra mussel establishment and spread (antifouling covers and filters). In this case, the replacement cost reveals both damages (impacts) and control measures (response).

- To confirm that reporting invasive species impacts in terms of ES boosts management responses, at least, in three ways: Firstly, it facilitates communication and stakeholders' deliberation about invasive species as an environmental problem. Secondly, it aids to develop monitoring schemes when the main policy objective is adaptation, a common situation in post-invasion contexts. And thirdly, it assists assessment of the (positive and negative) effects of the invaders and their distribution; through different assessment methods. Different examples in this respect can be found in contributions by different authors in the collective book by B. Rodríguez-Labajos et al. (2009).

4 Preparing responses in face of uncertainty: risk assessment, biopollution assessment and scenarios pre and post invasion

Managing change faces the challenge of future intrinsic uncertainties. Probabilistic predictions would support the instrumentation of decision-making tools based on the idea of efficiency (Perrings, 2005). Yet, as highlighted in the introduction, the existence of non-linear key drivers, reflexivity of human action in response to forecasts, and changes faster than the forecasting models (Walker et al., 2002) makes the generalisation of accurate quantitative forecasting methods difficult for the study and management in changing ecosystems. This opens the door to the use of alternative research tools and approaches in instances of socio-environmental systems and policies interplay, such as the case of the invasions of zebra mussel and invasive fish in Catalonia. This chapter explores three approaches for addressing the uncertainties in preparing responses to bioinvasions.

For many years, the debate for the allocation of scarce resources among potentially harmful AS under conditions of scientific uncertainty has been dominated by the attempts to improve **risk assessment** tools (Andersen et al., 2004; Gallardo and Aldridge, 2013). Developments in this respect are surveyed in **Section 4.1**, which offers an overview of the state of the question for the case of *D. polymorpha* and other aquatic invaders, such as *S. glanis*, in Catalonia.

It is argued that assessment of biopollution can also provide systematic appraisals to guide aquatic-AS management and facilitate risk communication to end users (Panov et al., 2009). A related discussion, mentioned in **Section 1.3**, is to what extent the existing **indices to assess biopollution or biocontamination** offer information that may be redundant with the state indicators used to evaluate biological quality of the water bodies. This discussion, for the specific application of fish invaders in Catalonia, is developed in **Section 4.2**.

Recently, interest in **scenario analysis** has grown as the role of uncertainty and the need for interdisciplinarity in policy making became increasingly better understood. The scenario approach is now widely seen as a valuable analytical device for integrated analyses of sustainability and a key aid in decision- and policy-making processes (EEA, 2009; Wehrmeyer et al., 2003; Wiek et al., 2006). While many scenario studies have been published over the years, global scenarios (e.g. Carpenter et al., 2006; Gallopin et al., 1997) and scenarios addressing particular issues in isolation, such as energy, climate change, water or European Union (EU) enlargement (e.g. Bertrand et al., 1999; Gallopin and Rijsberman, 2000; IPCC, 2007; Mooij, 2003) are the most popular. Scenarios concentrating on a particular local geographical area have become more important in recent years (Anastasi, 2003; Kok et al., 2006b). **Sections 4.3** report the results of two different approaches to scenario analysis in the context of aquatic bioinvasions in Catalonia, which built on outcomes from the previous chapters.

Each one of these three approaches will be analysed in the light of their usefulness to support management measures. Specific recommendations about their use for guiding policies for AIS prevention and control will be also included at the end of each section.

4.1 Tagging a species as a hazard: what we need to know about risk assessment[15]

At the arrival of a new species the type of concerns of the managers are usually very simple. Which species is this? What kind of damages it can cause? Is it really established or will spontaneously collapse? Can the species be eradicated or at least controlled? Does it constitute a real threat, and why? The scientific response to these relatively basic questions is not always straightforward. Data requirements and gaps, complex protocols and results of difficult interpretation may be involved in the assessment of risks, which eventually leads to organising social views and responses towards AS.

The purpose of this section is to overview the use of risk assessment as a management tool in the case of exotic species in aquatic ecosystems in Catalonia. After an overview of the approaches to risk assessment of alien species, and the actual implementations in Catalonia for the assessment of aquatic bioinvasions, the challenges for a further development of risk assessment approaches and tools are discussed.

4.1.1 Definition and approaches to risk assessment for alien species

The EEA (2010:8) defines risk assessment as "*the evaluation of the likelihood of entry, establishment or spread of an alien species in a given territory, and of the associated potential biological and economic consequences, taking into account possible management options that could prevent spread or impacts. Risk assessment includes risk analysis (process of evaluating biological or other scientific and economic evidence to determine whether an alien species will become invasive) and risk management (evaluation and selection of options to reduce the risk of introduction and spread of an invasive alien species).*" At a smaller scale context, the Spanish Catalogue of AIS (BOE, 2013: Art.2) indicates that risk assessment "*refers to the scientific-technical evaluation of the likelihood and consequences (of the risk) of introduction and establishment of an alien species in the natural environment and the measures that can be applied to reduce or control such risks*[16] "

Two good overviews on the formulation of methods and processes of risk analysis for invasive species can be found in a special issue summarising findings of a workshop *ad hoc* organised by the Society of Risk Analysis and the Ecological Society of America (Andersen et al., 2004), and in a study comparing the effectiveness and utility of existing risk assessment protocols for exotic species produced at the Radboud University Nijmegen, in the Netherlands (Verbrugge et al., 2010). Building also on Clarke et al. (2004), the different approaches to assess the risk of bioinvasions can be grouped as follows:

[15] This section benefits from the collaboration in the preparation of the document '*Avaluació de l'estat i el risc d'invasió per espècies exòtiques dels ecosistemes aquàtics de Catalunya*' [Evaluation of state and risk of alien species invasion in Catalonia's aquatic ecosystems] (Andreu et al., 2011) and from the participation in the seminar 'Risk assessment of biological invasions in aquatic ecosystems: methodological review and management proposals' (CREAF-ACA, Bellaterra, 30/11/2011), with the presentation 'Challenges for the consideration of risk assessment in the preventive management of aquatic ecosystems'. The title of the section is based on that of the well-known paper '*Risk analysis for biological hazards: what we need to know about invasive species*' (Stohlgren and Schnase, 2006).

[16] *Análisis de riesgos: Se refiere a la evaluación científico-técnica de la probabilidad y de las consecuencias (del riesgo) de la introducción y establecimiento de una especie exótica en el medio natural y de las medidas que pueden aplicarse para reducir o controlar esos riesgos*. (Free translation by the author).

- *Qualitative risk identification*. It is the less sophisticated approach although it requires a high level of expertise about bioinvasions, because it is based on parameters obtained from experience, as well as on consolidated principles and relations in the knowledge of invasions. Usually the outcomes are classifications of items (e.g. species, sites) in scales of 'low', 'medium' and 'low' risk. This approach might involve a degree of subjectivity and tends to overestimate events of low likelihood and high impact, and underestimate the events of high likelihood and low impact. An example of this type of protocols is Haugom et al. (2002).
- *Semi-quantitative risk rankings*. This intermediate approach aims at enhancing objectivity of the assessment, by improving the clarity of the employed process, and avoiding subjective perception of risk. These methods make use of quantitative data, thus obtaining rankings in a cardinal scale, which facilitate the comparison of results. Sandvik et al. (2013) provide an example of this approach.
- *Quantitative valuation of risks*. This is the most comprehensive approach. It aims at developing a probabilistic analysis of risk for the different adverse events (introduction, establishment, impact), including confidence intervals that can indicate the reliability of the estimates. This approach requires a remarkable amount of data gathering and analysis, including characteristics of the species, characteristics of the environment and its uses and the management measures applied. For this reason, it demands significant resource availability, computing tools, and use of sophisticated methods, some of them still under development. This, together with a tendency to oversimplify system functioning, may make it inappropriate for assessing environmental risks (GEF-UNDP-IMO and WMU, 2013).

From the point of view of how the approaches are used, another classification of the risk assessments could be on what is the item the risk of which is assessed. In this respect, there are three possible types of assessments:

- *Assessment of species risk*: they rank species according to their invasiveness potential, scoring both quantitative and qualitative elements such as the biogeography and history of the species, the presence of the so-called 'undesirable traits' that make it prone to be an invader, and species biology and ecology. The best established protocols in this respect are the Australian Week Risk Assessment (WRA, Pheloung et al., 1999), the Freshwater Fish Invasiveness Scoring Kit (FISK, Copp et al., 2009, 2005) – or its adaptation for freshwater invertebrates (Tricarico et al., 2010). In the case of plants, these kind of screening protocols correctly rejected 82-100 percent of invaders, whereas a less consistent range of 56-87 percent of non-invaders have been correctly accepted (Gordon et al., 2008).

  After several years of implementation, some of these protocols are being now put into question due to the excessive association of results to a small set of the assessed elements (Weber et al., 2009) and insufficient accuracy (Hulme, 2012; Onderdonk et al., 2010). Still, they may have a valuable role in the implementation of multi-stepped risk assessment protocols, such as the UK Risk Assessment Scheme (Baker et al., 2008; Booy et al., 2006), where a rapid assessment of risk of species helps to decide whether a detailed risk assessment is further needed or there are already elements to raise preventive or control measures.

- *Assessment of habitat risk*: they aim at describing the vulnerability of a habitat to bioinvasions. They often have a spatial reference and make use of geographic information systems (GIS) in which the different layers offer information about conditions that play a role in the invasion, such as infrastructure, habitat types, navigation routes, etc. Examples of this are the various reports produced by the Global Ballast Water Management Programme (GloBallast) assessing the ballast water risk for ports in different parts of the world (e.g. Anil et al., 2004; Awad et al., 2004; Clarke et al., 2004).
- *Integrated species/habitat risk:* they describe the potential spread of a given species in the territory, taking into account the match between the characteristics of the species and certain attributes of the territory. They use maps to illustrate potential future distribution or risk levels. For this, they can be based on statistical models, such as the case of the distribution risk for *Aedes albopictus*, tiger mosquito, in Europe (ECDC, 2013). Another example, explained below in more detail, is the index MZ-Cat, which calculated the susceptibility of some water bodies to the invasion of *D. polymorpha* in Catalonia.

4.1.3 Risk assessment implementations for aquatic species in Catalonia

While risk assessment for alien species is commonly employed in regions of the world where there is a certain tradition of AIS management, the implementation of risk assessments for aquatic species in Catalonia is relatively recent.

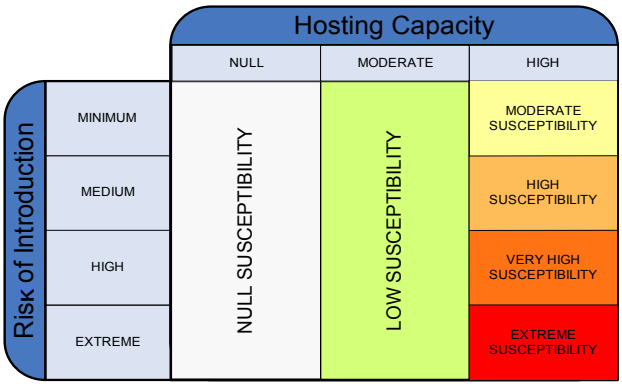
In the case of *D. polymorpha*, a document commissioned by the Catalan Ministry of the Environment from the University of Lleida estimated a vulnerability index for the main reservoirs of Catalonia based on zebra mussel ecological traits, recreational characteristics, river connectivity and potential impact (DGMN, 2005). This is possibly the first risk assessment exercise developed in Catalonia for aquatic AIS. Later on, the main researcher in charge of this study extended the calculation to 89 water bodies of the Ebro river basin (Palau et al., 2008).

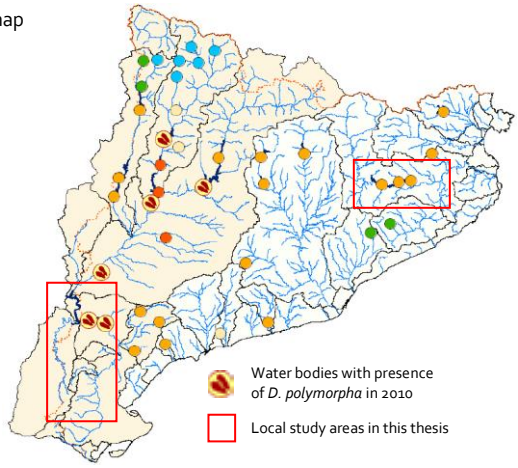
While being decisive to design monitoring measures (cf. ACA, 2007b), an issue of this methodology is that it provided scoring-based ranking relying on the aggregation of different elements of risk and hazard (introduction, establishment and impacts). Besides that, the knowledge about the ecological characteristics of the species in the Iberian watersheds improved over time, after the publication of this first assessment.

For these reasons, a new evaluation was commissioned by ACA, which lead to the definition of the susceptibility index MZCat (ACA, 2010c). This index takes into account two components. On the one hand, the analysis of factors facilitating the introduction of the zebra mussel into a water body – such as the situation and connectivity of the water body, accessibility or the type of recreational activities undertaken – allows calculating the Risk of Introduction (RI) of the species in a that water body. On the other hand, the factors (either physico-chemical, biological or hydraulic) that determine the capacity of a water body to satisfy the ecological requirements of the *Dreissena polymorpha* lead to estimate the Hosting Capacity (HC) of that water body. From there, the combination of both elements through the definition of critical values for RI and HC determines the different levels of susceptibility to the invasion, from null to extreme (**Fig. 37**). In addition to these two components of risk, supplementary modules of potential environmental and economic hazards are also provided.

Fig. 37 Schematic representation of MZCat levels and results for the assessed water bodies in Catalonia (in 2010)

Source: ACA (2010c) and Cia-Abaurre (2011); local study areas added in the map





The results of the assessment in 2010, also shown in **Fig. 37**, pointed out a generalised situation of high susceptibility in Catalan reservoirs. In particular, the situation for the study areas in this dissertation was not favourable. The water bodies in the Ebro River were already colonised, and obviously their susceptibility level was 'extreme'. The study area in the Ter River (comprising the Sau, Susqueda and Pasteral reservoirs) offers optimal conditions for the development of the zebra mussel (their HC is high). This means that there are not only good environmental conditions for the establishment and survival of adult individuals, but also for their growth, reproduction and further spread. Simultaneously the recreational activities in the reservoirs, linked to navigation in the case of Sau and to angling in all cases, make the risk of entry relatively high. Therefore, the degree of susceptibility to the invasion is 'high'. In La Baells Reservoir, in the Llobregat River, where the susceptibility level was also 'high', linked to the same conditions, the invasion was confirmed in 2011. This gives alarming signals for the management of the species in the IBC.

Besides portraying the risk levels and clarifying the elements or such risk (either related with factors of introduction or factors of establishment) the assessment was then linked to the planning of specific management measures for each water body according to its susceptibility level (ACA, 2009a). These measures were related with frequency of monitoring, conditions for navigation, and protocols in case of detection, including the advisability of different control treatments. In the IBC, the conditions for navigation were indeed included in the technical guidelines in the declaration of responsibility for navigation in the Internal Basins of Catalonia (ACA, 2014d, 2009b) (see example in **Section 1.4.4.d**). As this planning was prepared in the contexts of increasing budget cuts for the public sector, little could be implemented though in relation to other measures planned, like signposting, control of access points to the reservoirs or increased frequency of monitoring.

In the case of alien fish, it is clear that their deliberate introductions, such as the one of the European catfish in the Ebro or in the Sau reservoir, were not validated through any prior risk assessment. In other countries, the case of *S. glanis* has been employed as an example of the difficulties to predict whether a species will become problematic (Hil et al., 2005). Thus, a risk assessment validated by the British Department of Environment, Food and Rural Affairs (DEFRA), used for proposals to introduce non-native fish species, identified the Wels catfish *Silurus glanis* as low risk (Waters, 2004). Despite

anecdotal information pointing at increasing abundance in the natural environment, the species itself seems to remain at low numbers (Copp et al., 2007). However, parasitological examinations of released individuals from still-water fisheries revealed the presence of the non-native parasites *Thaparocleidus vistulensis* and *Ergasilus sieboldi*, the latter known to be an important fish pathogen (Reading et al., 2011).

In Catalonia the first risk analysis for alien species with the purpose to guide public management was prepared by Andreu et al. (2011). The assessment used the WRA and FISK protocols (see **Section 4.1.1**), together with an adaptation for mammals and herpetofauna arranged *ad hoc*. The evaluation included 64 species, most of them macrophytes and riverbank plants (39 sp) and fish (21 sp). Focussing on the results for fish, evaluated with the FISK protocol, the results are those shown in **Table 37**.

Table 37

Results of the risk assessment for some alien fish species

Source: Data from Andreu et al. 2011

Risk	Scoring range	Species
Very high	≥ 36	*Pseudorasbora parva; Cyprinus carpio*
High	26-35	*Carassius auratus; Carassius carassius; Salvelinus fontinalis; Silurus glanis; Ameiurus melas; Micropterus salmoides; Scardinius erythrophthalmus*
Medium	21-25	*Gambusia holbrooki; Perca fluviatilis; Rutilus rutilus; Tinca tinca; Lepomis gibbosus; Alburnus alburnus; Esox lucius; Sander lucioperca; Abramis brama*
Uncertain	≤ 20	*Fundulus heteroclitus; Misgurnus anguillicaudatus; Blicca bjoerkna*

Not surprisingly, species like *Pseudorasbora parva* and *Cyprinus carpio*, widely distributed in Catalonia, show high scores and can be considered as 'very high risk' species. *S.glanis* is among the species classified as 'high risk' together with other fish used in angling like *Carassius auratus*, *Salvenilus fontinalis* and *Micropterus salmoides*. As indicated in **Section 1.2.2**, on the management of fish invaders, these four latter species have been exceptions in the angling regulation in force. For instance, there is an obligation of catch-and-release of *Carassius auratus* (and also *Cyprinus carpio*) when used for angling. As the fishing law is the only measure applied in general to control alien fish, this means that two of the top risk species in practice are not controlled at all. A similar exception applies in some specific water bodies for the other high-risk fish mentioned here.

Andreu et al. (2011) include three additional remarks on these result. First, among the assessed species there are three that are not considered to be established yet in the Catalan water (*Abramis brama*, *Carassius carassius* and *Salvelinus fontinalis*). The first one showed a relatively low score, the lowest among the 'medium risk' species, while the other two are at the top of the high risk species. These differentiated results are thus helpful to prioritise control measures towards the species of higher associated risk.

Second, among the 'medium risk' species there is *Gambusia holbrooki*, Eastern mosquito fish. To find this species at the lowest risk range is surprising because this is one of the species which actual impacts in native fauna have been proved in Catalonia. The authors explain that this is due to the fact that the methodology does not assess the intensity of the impacts suffered but rather their variety. As the literature does not confirm further impacts besides competition for *G. holbrooki*, the scoring of this

species is lower than for other species with broader scope of impacts, even at lower intensity. This is a warning in relation to the use of results, and it is related to the feared type II errors (false negatives) a critical issue in risk analysis. There have been suggestions to tackle this issue by incorporating the magnitude and duration of expected impacts in the assessment (Underwood and Chapman, 2003)., by independent testing of the analyst (Miller et al., 2012) or through adaptative management (Matsuda, 2002).

Third there are three species which lower scoring should not be interpreted as low risk but as uncertainty. The outcome is explained as the lack of information to reach a reliable assessment. In this case, the recommendation is to proceed to a second-step in the assessment where a more precise evaluation is undertaken.

In fact, ignorance is recognised as a major issue in risk analysis (Aven and Steen, 2010). Information about species is often unavailable and the evaluator needs to answer 'don't know' to questions related to aspects that are poorly studied. In this case, the methodological guidelines suggest to rank the species as 'high risk', as a precautionary measure – that is to equal 'unknown' with a 'yes' response –, and to inform about the proportion of questions that could not be answered as a way to gauge the level of confidence associated with the assessment (Copp et al., 2005).

4.1.3 Challenges for the consideration of risk assessments in the management of alien species

Risk assessment is usually considered as a mainly scientific process (GEF-UNDP-IMO and WMU, 2013) to inform persons in charge of risk management about both priorities of management and possible options for risk mitigation. The scientific community sometimes objects to the real scientific nature of risk assessment, over all when it relies on qualitative or semi-quantitative approaches (Andersen et al., 2004). Still, it is recognised as a reasoned way to formulate cost-effective policy measures. Although prevention is usually associated with the idea of avoiding AS entry, there are negative outcomes that can be prevented along the whole invasion process, as shown in **Table 38**.

Table 38

Type of risks along the invasion process

Source: Own elaboration based on Andreu et al. 2011

Invasion phase	Associated risks
Introduction and release	Risk of entry for species present in surrounding territories that are likely to be transported
Establishment	Risk of establishment for species recently introduced
Impact	Economic hazard, environmental hazard or hazards to human health
Dispersal	Risk of dispersal for species already present, given their dispersal mechanisms

As a part of a preventing approach, risk assessment can guide costly monitoring efforts. For instance, in the case of zebra mussel in Catalonia, the monitoring grid excluded some high-mountain water bodies because the likelihood of establishment was null there (see **Fig. 37**). Risk assessment can also support the planning of measures for early detection and rapid response (EEA, 2010). For instance, Gallardo and Aldridge (2013) suggest the prioritisation of resources through assessing environmental suitability maps for short lists of potential future invaders. Besides preventing entry, the identification of high risk species and areas can be helpful to prioritise control measures and efforts for the mitigation of impacts.

In face of this, is it necessary to design a risk assessment approach for Catalonia? There are at least two types of reasons that could justify the development of such an approach.

On the one hand, there are environmental reasons. The preamble of the Council Regulation (EC) No 708/2007 concerning use of alien and locally absent species in aquaculture (OJEU, 2007) indicates that: "[*t*]*he potential risks, which may in some cases be far reaching, are initially more evident locally. The characteristics of local aquatic environments throughout the Community are very diverse and Member States have the appropriate knowledge and expertise to evaluate and manage the risks to the aquatic environments falling within their sovereignty or jurisdiction*." In this light, different European countries (such as Austria, Belgium, Germany, Ireland, Switzerland and the United Kingdom) have developed their own national protocols for risk assessment of species. The comparison of their (dissimilar) results confirms the need of lower-scale evaluations, since the match between species-climate and species-environment changes between countries and biographic regions (Verbrugge et al., 2010).

On the other hand, social reasons may also advise to generate a risk assessment proposal from the regional context. Among the factors to take into account there are socio-economic aspects such as the identification of likely impacts and costs, the containment potential, the opportunity and no-action costs, and regulatory mandates and social considerations (Stohlgren and Schnase, 2006). The scope and relative relevance of these factors are better known at the regional context.

Moreover, the conceptual framework of the future European strategy of AIS foresees the development of a common approach in relation to the terminology, risk assessment and possible listing of invasive alien species of Union concern (EC, 2008; EEA, 2010). How is Catalonia preparing the contribution to this debate? A coordinated approach has numerous advantages and is undoubtedly a need for the common response to the AIS issue. It could be argued though that top-down common standards should be approached with caution.

Take, for instance, the Council Regulation concerning use of alien and locally absent species in aquaculture (OJEU, 2008b). The Regulation establishes a framework for aquaculture practices in relation to AS, in order to minimise their possible impacts on aquatic habitats. For this, strict risk assessment procedures should operate before authorising their management, but this provision does not apply to a list of exceptions. The species in this list are shown in **Table 39**, together with their associated risk according to the available calculations by Andreu et al. (2011). Clearly, in this case this regulation for aquaculture is not adequately protecting the Catalan ecosystems and this kind of information can be employed in argumentations in case of future developments of this norm.

Table 39

Associated risk for the exempted species in the Council Regulation concerning use of alien and locally absent species in aquaculture

Source: OJEU (2008b) and Andreu et al. (2011)

Species	Risk	Species	Risk
Acipenser baeri	n.a.	*Cyprinus carpio*	Very high
A. gueldenstaedti	n.a.	*Huso huso*	n.a.
A. nudiventris	n.a.	*Hypophthalmichthys molitrix*	n.a.
A. ruthenus	n.a.	*Ictalurus punctatus*	n.a.
A. stellatus	n.a.	*Micropterus salmoides*	High
A. sturio	n.a.	*Oncorhynchus mykiss*	n.a.
Aristichthys nobilis	n.a.	*Ruditapes philippinarum*	n.a.
Carassius auratus	High	*Salvelinus alpinus*	n.a.
Clarias gariepinus	n.a.	*Salvelinus fontinalis*	High
Coregonus peled	n.a.	*Salvelinus namaycush*	n.a.
Crassostrea gigas	n.a.	*Sander lucioperca*	Medium
Ctenopharyngodon idella	n.a.	*Silurus glanis*	High

From the above, some final ideas can be outlined in relation to desirable attributes of risk assessments for practical support to public policy choices.

- From the analytic point of view the following attributes are of particular relevance for management:
  - Accuracy. Since the resources for management are limited, particularly in the area of water management, the appraisal should enable a rapid distinction of the most problematic species. Accuracy of results also involves the minimisation of false positives, not only to prevent resource waste but also to avoid unnecessary indirect impacts of AS management.
  - Adaptability of the method. The method needs to be easily revised and adapted to improve its applicability and predictive capability.
  - Traceability of results. The results of the assessment must be traceable and easy to explain to the public at large. The base information needs to be ready for possible updates and, if needed, reviews by external evaluators.
- From the point of view of the integration of results into management practices other desirable attributes are:
  - The risk assessment should not be an isolated exercise, but rather be part of a well-articulated system of early alert and rapid response. Assessments for species still absent for the managed territory but present nearby are particularly useful.
  - When the purpose is to prioritise the implementation of control or eradication measures, it is important to use resources with a clear guide. For this purpose, rankings are more useful than block categories.
  - In the case of the most problematic species and territories, the approach needs to facilitate the management of the different stages of the invasion processes. Therefore, rather than final scores, the combination of indices for the different stages (introduction, establishment, impact) and their relation with the environmental and socio-economic conditions of the territory are advisable.
  - Ideally, the results should be clear signals in terms of management, linked to regulatory mechanisms (e.g. black lists, restrictions, suspensions, containment, etc.) along a pre-specified roadmap of management.
- Having in mind the relation of AS management with the fulfilment of the WFD, certain conditions of risk assessments are desirable:
  - It is important to link the result of the risk assessment with the assessment unit of the WFD, the water body. The risk assessment units should be the water bodies rather than the species.
  - The risk assessment protocol should ensure to include potential impacts over relevant quality elements. The determination of the risk level for the water bodies could take into account the current state of the water body to rate differently the introduction of certain risk species, over all for those water bodies which good status should be maintained.

These latter points link with the contents of the following section. The use of risk assessment tools provides results that can guide programmes of measures for the ecological improvement or maintenance of water bodies. Under the WFD, there are already indices designed with the purpose of tracking the progress made and monitoring certain biological quality elements. Are these two lines of work redundant each other?

4.2 The use of biopollution indices in support of increased ecological quality[17]

4.2.1 Framing the discussion

As mentioned in **Section 1.4**, one of the challenges of integrating AS in the management of the ecological status of water bodies, and hence water quality, is that AS are at the same time a pressure to ecological status and a component of the biological elements assessed to evaluate ecological status. This issue was a matter of two technical workshops in 2008 and 2009 of the WFD Ecological Status Working Group (ECOSTAT), with the participation of this author.

In search of a harmonised European approach, ECOSTAT pondered whether AS should be taken into account in the WFD assessment. The starting point was that the Annex V of the WFD states that "*water bodies should be 'totally or near totally undisturbed'*" in the reference condition. An interpretation of this is that WFD precludes the presence of AS at high quality status (Phil Boon, pers. comm.,02/04/2008). From there, it follows a deliberation about how the impacts of AS are captured in the assessment tools for ecological status classification. The use of supplementary biocontamination & biopollution (BC&BP) indices is one among several options favoured by the national authorities in charge of implementing the WFD (Vandekerkhove and Cardoso, 2010). However, the normal status classification usually relies on the match between the quality classes and differentiated effects of stressors, which would be a good property to maintain in the integration of AS to the assessment (Cardoso and Free, 2008; Vandekerkhove et al., 2013). In the final recommendations of the ECOSTAT workshops, the critical importance of methods for identifying risk and the need to test biopollution indices across all types of surface waters is pointed out, including their application to the procedures of the WFD (Lee, 2009).

It will be remembered from **section 1.4** that biopollution is defined as the adverse impacts of invasive alien species at the level that disturb ecological quality by effects on one or more levels of biological organization: individuals (such as internal biological pollution by parasites or pathogens), populations (by genetic change, e.g. hybridization), communities (by a structural shift), habitats (by modification of physical–chemical conditions), or/and ecosystems (by alteration of energy and organic material flow) (Olenin et al., 2011). As an effect, socioeconomic costs may be also associated with biopollution.

[17] The author benefited from her participation in the formal discussions on alien species and water body classification for the WFD Ecological Status Working Group (ECOSTAT) in Bordeaux (2008) and Ispra (2009), both coordinated by Professor Phil Boon (SNH, UK) and Dr Ana Cristina Cardoso (JRC, Italy). The author gratefully acknowledges the participants for the fruitful discussions, in particular Jochen Vandekerkhove (JRC, Italy), for the ECOSTAT questionnaire to national experts 'Alien species and the Water Framework Directive' issued in January 2009. Along the process, joint discussions with Dr Antoni Munné and Dr Carolina Solà have enriched the empirical background and the narrative of this section.

In this respect, the purpose of this section is to present results of the applicability of the most well-known BP&BC indices available in the literature (**Table 40)** using information from the standard monitoring programme in Catalonia. As a part of this exercise, the pertinence of the results is evaluated by answering two questions: 1) are the BP&BC indices actually state indicators, i.e. do their results respond to indicators of pressures to the water bodies?; and if so, 2) are the indices redundant with the existing indicators of state for a given biological element? Note that this discussion will be done in relation to the overall aim of this chapter, related with the use of information on AS for the purpose of management, and the ensuing role of uncertainty in the assessments.

Table 40 Biopollution and biocontamination indices from the literature

Index	General description	Data requirements
SBC – Site-specific Biological Contamination Index (Arbačiauskas et al., 2008)	Based on AS richness and abundance	- AS richness and relative abundance per assessment unit
IBPR – Integrated biopollution Risk Index (Panov et al., 2009)	Risk-based approach with reference to the proportion of AS with potential to spread, establish and cause impact	- AS richness and relative abundance per assessment unit - Evidence of AI impact (either on native biodiversity, ecosystem functions, trophic production, human access to natural resources, human, domestic animal and plant health, recreational and aesthetic activities, infrastructure or control costs)
BPL – Biopollution Level Index (Olenin et al., 2007)	Based on the abundance and distribution of the species and their impact in communities, habitats and ecosystem functions	- AS relative abundance and distribution within each assessment unit - Evidence of AS's impact on native species of communities, on habitats and on ecosystem functioning per assessment unit

4.2.2 Applicability of biopollution and biocontamination indices in Catalan rivers, a test using fish species

The study area for the test includes 23 watersheds bounded by the administrative limits of Catalonia. As the region features to Mediterranean climate, half of the watersheds comprise ephemeral streams. The dataset includes information from sampling sites along the different river typologies present in the study area; occasionally some of the water bodies containing more than one site. Environmental and fish community data were available from sites sampled in 2002-2003 (n_{s2003}=333) and 2007-2008 (n_{s2008}= 311) as a part of the routine monitoring program run by the watershed authority, the Catalan Water Agency (ACA, 2006a; Sostoa et al., 2010). In the case of fish, the BIORI protocol secures obtaining the parameters needed for the estimation of the indices SBC and IBPR, namely AS richness and relative abundance per assessment unit. In particular, abundance is registered both in terms of density (individuals / ha) and in terms of biomass (kg / ha) (ACA, 2006a).

It is worth noting that there is absence of fish in 19,5 percent (in 2002-2003) and 24 percent (in 2007-2008) of the monitored sites due to diverse circumstances. Examining the data for the period 2002-2003, whereas 2 percent were sites with a dry river bed – i.e. ephemeral streams without fish according to historical data – or offered bad conditions for fishing (another 2 percent), there is a remarkable 15 percent of sites were the absence of catches indicates adverse conditions for the survival of the fish fauna, clearly in relation to ecological quality conditions.

Table 41

Number of sampling sites across different conditions

Source: Estimated based on data provided by ACA

Number of items	2002-2003	2007-2008
Total sites (n_S)	333	311
Sites without catches (no fish, dry river bed or bad conditions for fishing)	65	76
Sites with catches	268	235
Water bodies with catches (n_{WB})	182	235

Focussing on the sites with available information about the fish community and once contrasted the datasets of both monitoring periods this section analyses BP&BC indices in water bodies in 2002-3 (n_{WB2003}=182), and 2007-8 (n_{WB2008}=235). Comparisons are done intersecting available information in coincident water bodies.

The assessment of biopollution requires the characterisation of the species according to their native or alien status. This information was obtained from ACA (2006a) and Sostoa et al. (2010) and adapted through expert assessment for the case of *Salmo trutta*, *Anguila anguila*, and *Phoxinus phoxinus*.

a. Site-specific Biological Contamination Index (SBC), a reasonable quick assessment of state

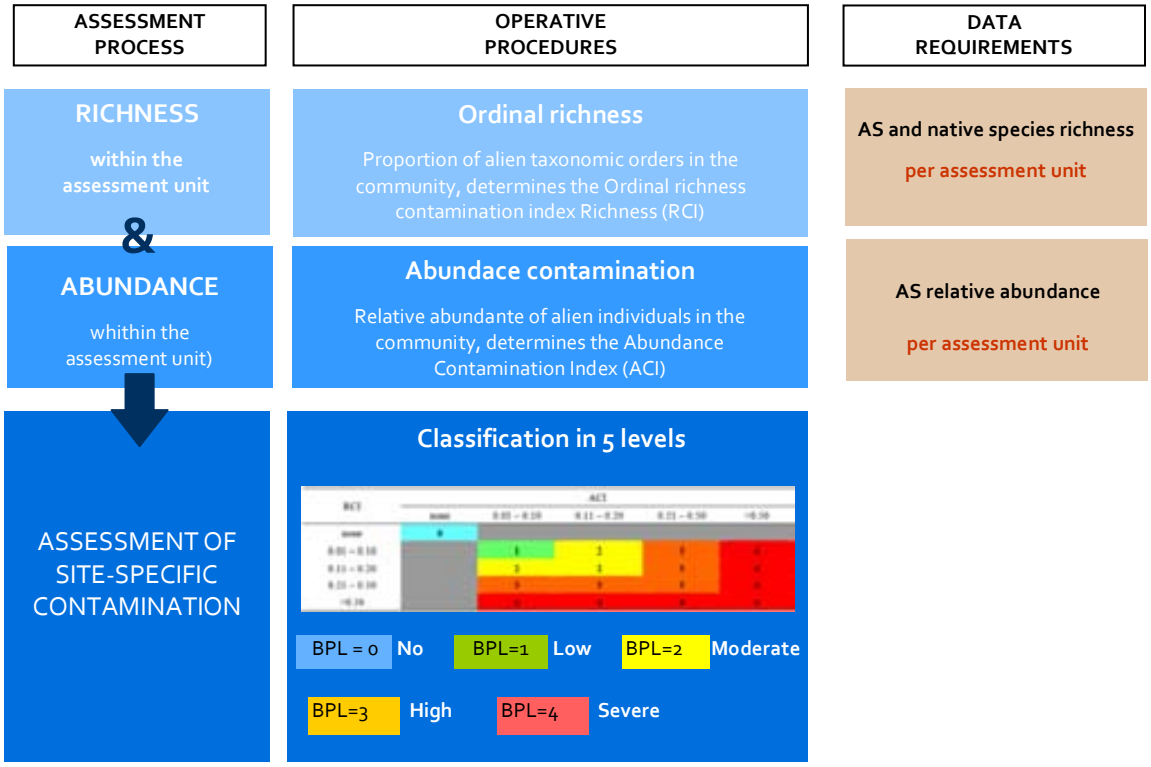
The Site-specific Biological Contamination index (SBC) enables the comparison of different aquatic ecosystems according to their level of pollution from new taxa, taking into consideration their relative abundance in the ecosystem (Arbačiauskas et al., 2008). Accounting for the proportion of alien taxonomic orders[18] in the community, and the relative abundance of alien individuals, the biocontamination can be classified in five levels from 'No' biocontamination (SBC=0) to 'Severe' biocontamination (SBC=5) and can be inversely interpreted as a contribution from the 'Very good' status to the 'Very bad' status of the aquatic ecosystem. The levels are determined through different thresholds in the proportion of species richness and/or the alien species abundance (see **Fig. 38**).

The initial testing done by the developers of this methodology for rivers of Central Europe used macroinvertebrate data compiled from different sources. After that, the SBC index was applied for the case of the Isle of Man, for macroinvertebrate data (MacNeil et al., 2010). In this case, the data consistently relied on the UK Environment Agency guidelines for monitoring sampling, similar to a well-known assessment system for ecological quality of rivers using macroinvertebrates. A similar exercise was undertaken by Šidagyte et al. (2013) for the case of invertebrates in Lithuanian lakes. There two later studies have the explicit objective of analysing the biocontamination results in relation to metrics of ecological status and/or to environmental stressors parameters. While in the first one there was a significant negative relationship between indicators of biological quality and the SBC indices, in the second case SBC indices were unrelated either with biological quality indices or with stressor variables. This information is relevant in the light of the analysis in **Sections 4.2.3** and **4.2.4**.

[18] Here the assessment is done for a taxonomic group within one phylum only (Chordata). Since detailed information about the species of fish was available, an adaptation of the methodology was to estimate the richness contamination index (RCI) based on species richness and not ordinal richness, which gives a finer grained picture of the situation. This adaptation was positively regarded by two biologists specialists in water quality indices and also discussed and validated with Dr. Kęstutis Arbačiauskas (pers. comm., Ispra 17-18/06/2009).

Fig. 38 Procedure for the determination of the site-specific biocontamination (SBC) level

Source: Own elaboration based on Arbačiauskas et al. (2008)



The SBC is not a risk index, since it does not point to possible negative outcomes but to actual adverse ecological consequences that percolate from the presence and abundance of AS. Once the data for the selected *taxa* is available, the calculation for a given assessment unit is relatively straightforward, though laborious. In Catalonia, the routine monitoring program for fish offers the possibility of determining the SBC index using indicators of abundance both in terms of the density (number of individuals per river hectare) and in terms of biomass (kilograms of alien fish per river hectare).

The results of the calculation (shown in **Appendix IV**) for the two assessment periods and the two possible metrics of abundance do not differ markedly depending on the metric used (density or biomass). Accordingly there is moderate and more than moderate biocontamination (suggesting less than good ecological status) in one third of the monitored sites (34 percent in 2002-3; 35 percent in 2007-8) and around one half of the sites with fish communities (47 percent in both campaigns). In both assessment periods, the results show a negligible worsening (involving 6 sites at the most) when biomass indicators are used, with minor decreases in moderate and high biocontamination and ensuing increases in high and severe biocontamination.

An issue in relation to the use of this indicator is getting polarised results. Most of the resulting biocontamination levels are concentrated at the extremes, as shown in

Fig. 39. Moreover, the presumption of alien species effects simply derived from the alien to native species ratios can be arguable as not all alien species are damaging. In any case, the SBC is an easy-to-estimate indicator based on the existing monitoring routines. It can be used for a quick assessment of

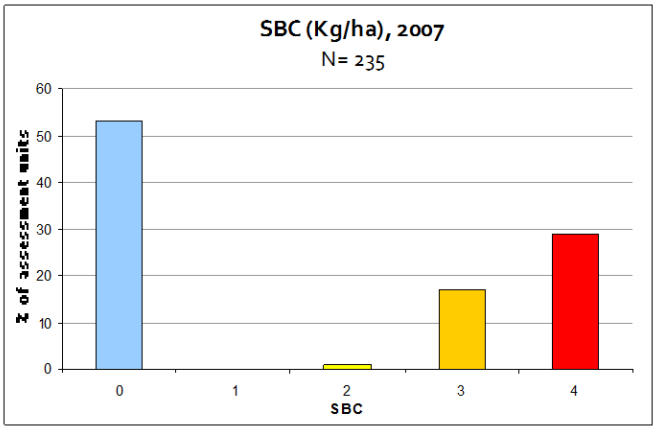
the state of biocontamination, provided that there is available data on relative AS abundance at the site level.

Fig. 39

Percentage of assessment units per SBC level (2007-2008, abundance as kg/ha)

Source: Estimated based on data provided by ACA

SBC index	Biocontamination	Water bodies (N.)
0	No	125
1	Low	0
2	Moderate	2
3	High	40
4	Severe	68
n.a	Without fish	76



b. Integrated biopollution risk (IBPR) index, a quick risk assessment

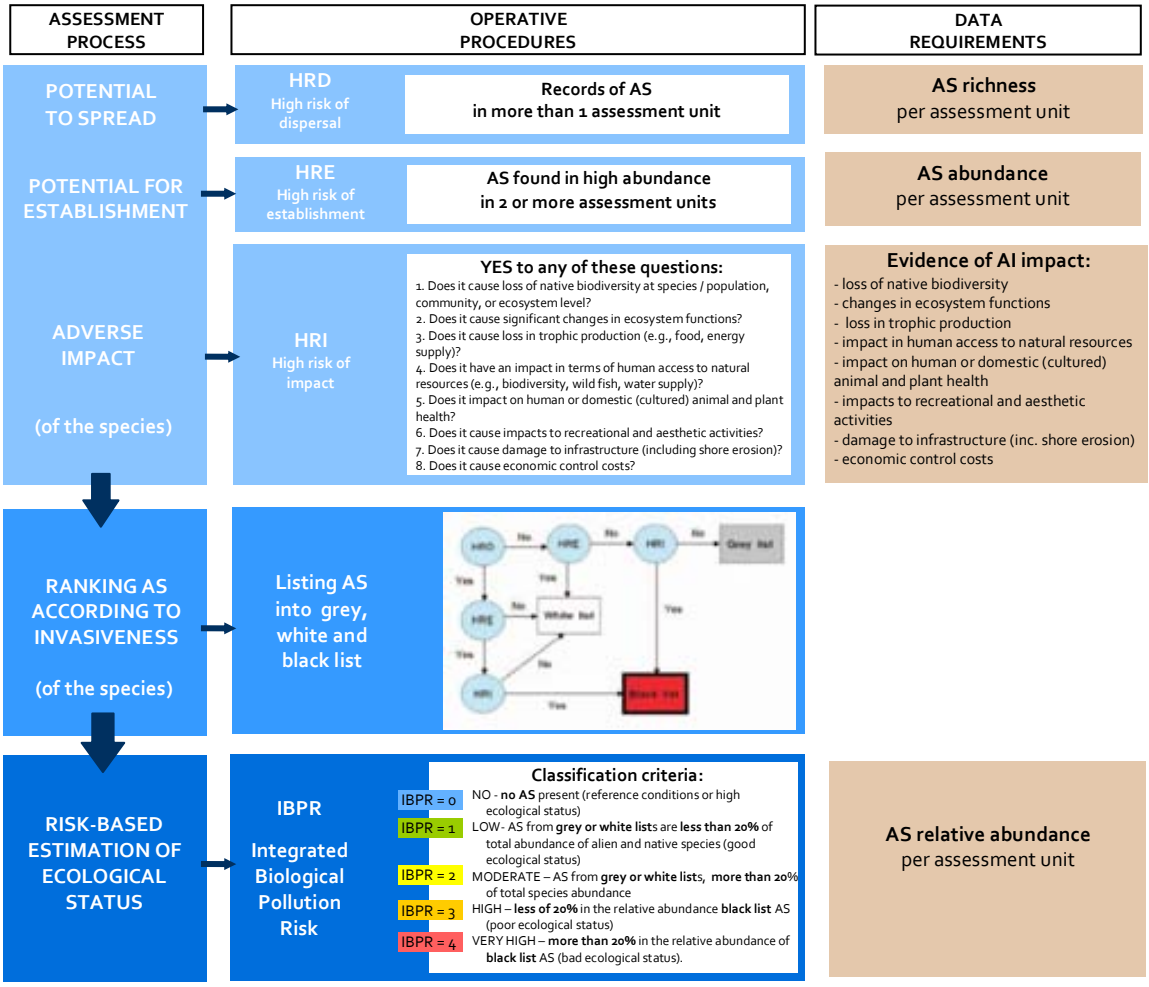
Relying on the assumption that risk-based assessments are useful to support cost-effective decisions consistent with the precautionary principle, Panov et al. (2007, 2009) developed an approach based on the general appraisal of invasiveness according to three elements of risk. Such elements are dispersal, establishment in new environments and generation of ecological and/or socioeconomic impacts, combined as shown in **Fig. 40**.

The authors also provide some practical guidelines for the evaluation of each one of the descriptors of risk (also indicated in that figure), which involves information about richness and relative abundance of AS in each one of the assessment units. Eventually the IBPR index, scoring 0 to 4, is estimated with reference to the proportion of species present in specific locations that are included in one or more of three lists (black, grey or white), classified according to a formal listing procedure.

The assessment does not require proof of actual impact in the assessment unit, but is entirely based on the existing information about the species' impacts according to the literature or other reliable source of knowledge. Of course, there are different methods to establish generic impact of species. Nentwig et al. (2010) propose a scoring system (0-5) using subcategories of environmental and economic impacts multiplying the total rating by the percentage of occupied area, and test it for alien mammals in Europe. Magee et al. (2010) estimate the magnitude of the stress caused *in situ* by alien species using an index that summarises the frequency of occurrence and the potential ecological impact, demonstrating the use in the case of streamside vegetation of a river basin. Sandvik et al. (2013) classify species determining their placement along the two axes (invasion potential and local ecological effect), using a list of specific criteria, such as mean expansion rate and interactions with keystone species. They test the proposed system for several AIS still absent from Norway, their geographic area of interest. In the case of the IBPR assessment process, the evaluation is rather simple, and only requires one positive response to a list of questions about possible types of ecological and socioeconomic impacts (see **Fig. 40**).

Fig. 40 Procedure for the determination of the Integrated biopollution risk (IBPR) index

Source: Own elaboration based on (Panov et al., 2009)



The idea of using standardised procedures to classify AS into grey, white, and black lists in order to provide a common framework for management is not new (Genovesi and Shine, 2004; Nehring and Klingenstein, 2008). The IBPR index builds on this background to propose a listing system involving the following lists:

a) Black, for species with high potential to cause impact, together with species that are with high potential to spread and establish; their presence should be prevented or deemed as an element of necessary control.

b) White, for species with high potential to spread and/or high potential for establishment but low potential to cause impact; their presence can be deemed as acceptable.

c) Grey, for species with unknown potential to spread, establish and cause impact; for precautionary reasons, the set of 'no' responses is not interpreted low risk potential for all risk elements, but as a need of continuous monitoring to expand knowledge about the species.

Using the information about the number of sites with presence of the species, their relative abundance and known impacts of the species from the literature, a classification of alien fish detected through the standard monitoring system in Catalonia is presented in **Table 42**. Note that, in the listing scheme presented in **Table 41,** 'yes' means that information on potential invasiveness of the species is available, while 'no' means information is not available or 'unknown'.

Table 42 Results of listing species according to the IBPR methodology

Note: **HRD -** High Risk of Dispersal, based on number of sites with presence of the species; **HRE** – High Risk of Establishment, based on the number of sites with relative abundance > 20%; **HRI** – High Risk of adverse ecological and/or socioeconomic Impacts

Source: Own elaboration based on data provided by ACA

Species	HRD (2003)	HRE (2003)		HRD (2007)	HRE (2007)		HRI	List (2003)		List (2007)	
		Ind/ha	Kg/ha		Ind/ha	Kg/ha		Ind/ha	Kg/ha	Ind/ha	Kg/ha
Alburnus alburnus	22	10	3	28	11	6	YES	Black	Black	Black	Black
Ameiurus melas	1	1	1	3	0	0	YES	Black	Black	White	White
Barbatula barbatula	5	2	0	9	4	0	NO	White	White	White	White
Barbus graellsii	26	13	13	25	5	9	NO	White	White	White	White
Carassius auratus	5	2	2	6	3	2	YES	Black	Black	Black	Black
Cyprinus carpio	62	21	39	57	13	32	YES	Black	Black	Black	Black
Esox lucius	1	1	1	1	0	0	YES	Black	Black	Black	Black
Gambusia holbrooki	11	9	1	16	11	2	YES	Black	White	Black	Black
Gobio lozanoi	5	1	0	11	5	1	NO	White	White	White	White
Lepomis gibbosus	18	5	1	23	10	5	YES	Black	White	White	White
Micropterus salmoides	5	1	0	6	0	0	YES	White	White	White	White
Misgurnus anguillicaudatus	N.A.	N.A.	N.A.	1	0	0	YES	N.A.	N.A.	Black	Black
Oncorhynchus mykiss	6	1	4	6	2	4	YES	White	Black	Black	Black
Parachondrostoma miegii	4	4	3	5	3	3	NO	White	White	White	White
Perca fluviatilis	N.A.	N.A.	N.A.	1	0	0	YES	N.A.	N.A.	Black	Black
Phoxinus sp.	18	13	2	31	23	13	NO	White	White	White	White
Pseudorasbora parva	1	0	0	7	0	0	YES	Black	Black	White	White
Rutilus rutilus	2	1	1	14	4	4	YES	White	White	Black	Black
Salmo trutta	9	4	6	3	1	1	YES	Black	Black	White	White
Sander lucioperca	2	0	0	2	0	0	YES	White	White	White	White
Scardinius erythrophthalmus	17	3	2	8	1	1	YES	Black	Black	White	White
Silurus glanis	5	0	1	6	1	4	YES	White	White	White	Black

Some comments stemming from the results on listing species are the following ones:

- All the species are classified either in the black or the white lists, and none within the grey one. According to the information on richness and abundance of the listed fish in Catalonia, the only species that could have been considered for the grey list are *Ameiurus melas*, *Esox lucius*, *Misgurnus anguillicaudatus*, *Perca fluviatilis*, and *Pseudorasbora parva*. In all cases, available information about impacts of these species has put them automatically in the black list.

- In 12 cases (55 percent of the assessed species) the classification is consistent between across periods and metrics of abundance, either black (*Alburnus alburnus*, *Carassius auratus*, *Cyprinus carpio*, *Esox lucius*) or white (*Barbatula barbatula*, *Barbus graellsii*, *Gobio lozanoi*, *Micropterus salmoides*, *Parachondrostoma miegii*, *Phoxinus sp.*, *Sander lucioperca*).

  It is worth noticing that the white-list species are either species native to the Ebro basin and other Iberian watersheds traslocated into the IBC – with meagre information about impacts – or high-impact AS which are not very abundant in the water bodies where they are present, which suggests low risk of establishment. Improved knowledge about the impact of the species or future increase in their abundance would result in a change of the classification from white to black.

- In the other cases the categorization changes between or within periods. In 5 cases (23 percent of the species) the classification changes between periods, for different reasons. Among the several casuistries, it is remarkable the case of *Rutilus rutilus*, that increases dramatically in distribution and relative abundance thus becoming a black-list species. In 3 cases (13.6 percent of the species), results for the same period vary according to the metric used for assessing the risk of establishment. This is related with species of high impact potential that may be locally abundant in numbers but which individuals are smaller in size compared with other caught fish of the community (*Gambusia holbrooki*, *Lepomis gibbosus*) or species with bigger size than other individuals of the community, although may not be as frequently caught (*Oncorhynchus mykiss*, *Silurus glanis*).

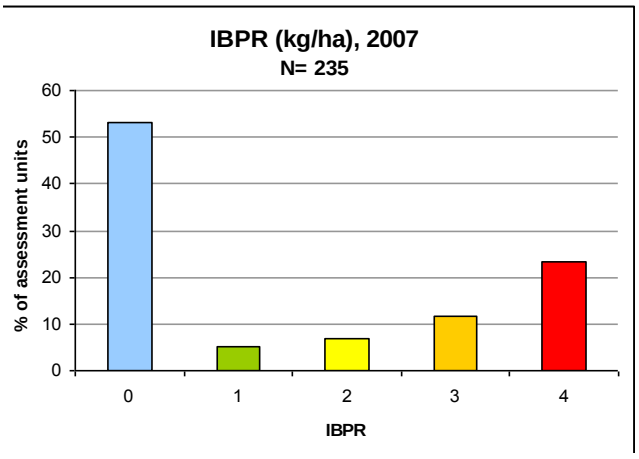
Based on these results about the species, and using the classification criteria mentioned in **Fig. 40**, the IBPR index for each one of the assessed water bodies can be calculated. The results for the two assessment periods (plotted in **Annex V**) are more distributed among classes than the ones of the BSC index. Yet they are still polarized results, as it is shown in **Fig. 41**.

Fig. 41

Percentage of assessment units per IBPR level (2007-2008, abundance as kg/ha)

Source: Estimated based on data provided by ACA

IBRP index	Biopollution risk	Water bodies (N.)
0	No	125
1	Low	12
2	Moderate	16
3	High	27
4	Severe	55
n.a	Without fish	76



Results differ slightly depending on the metric used (density or biomass). Using biomass indicators of abundance (kg/ha) tends to bring sites graded from the 2 (Moderate) and 3 (High) biopollution risk levels to the 1 (Low) and 4 (Severe) levels, as nearly symmetrical changes in the number of sites can be observed in relation to the assessment done with density indicators of abundance (individuals/ha).

This is probably due to the high abundance of small-sized white-list species. In general, the effect is to obtain slightly worse general results when using indicators of abundance based on fish density. Accordingly, there is an indication of moderate and more than moderate biopollution risk (suggesting less than good ecological status) in one third of the monitored water bodies (29 percent to 33 percent) and around 40 percent of the water bodies with fish communities.

Table 43

Percentage of sites with moderate and more than moderate biopollution risk using the IBPR index

Source: Own elaboration based on data provided by ACA

Campaign	Number of items	Percentage IBPR [2,3,4]	
		Density (ind/ha)	Biomass (kg /ha)
2002-2003	Total monitored sites	32	29
	Sites with fish	40	36
2007-2008	Total monitored sites	33	32
	Sites with fish	40	42

In summary, the IBPR methodology offers a feasible process to assess potential biopollution in different water bodies in Catalonia, based on certain operative assumptions on the impacts of the species. As a risk index, IBPR method is helpful to frame the need for management with an account of possible impacts of AS. The method does not require proof of actual impacts and therefore does not distinguish properly the different effects that the same species may have in different hosting ecosystems. Besides the results for the different assessment units, the process provides with a (non-stable) classification of alien species according to their potential invasiveness, also a useful management tool.

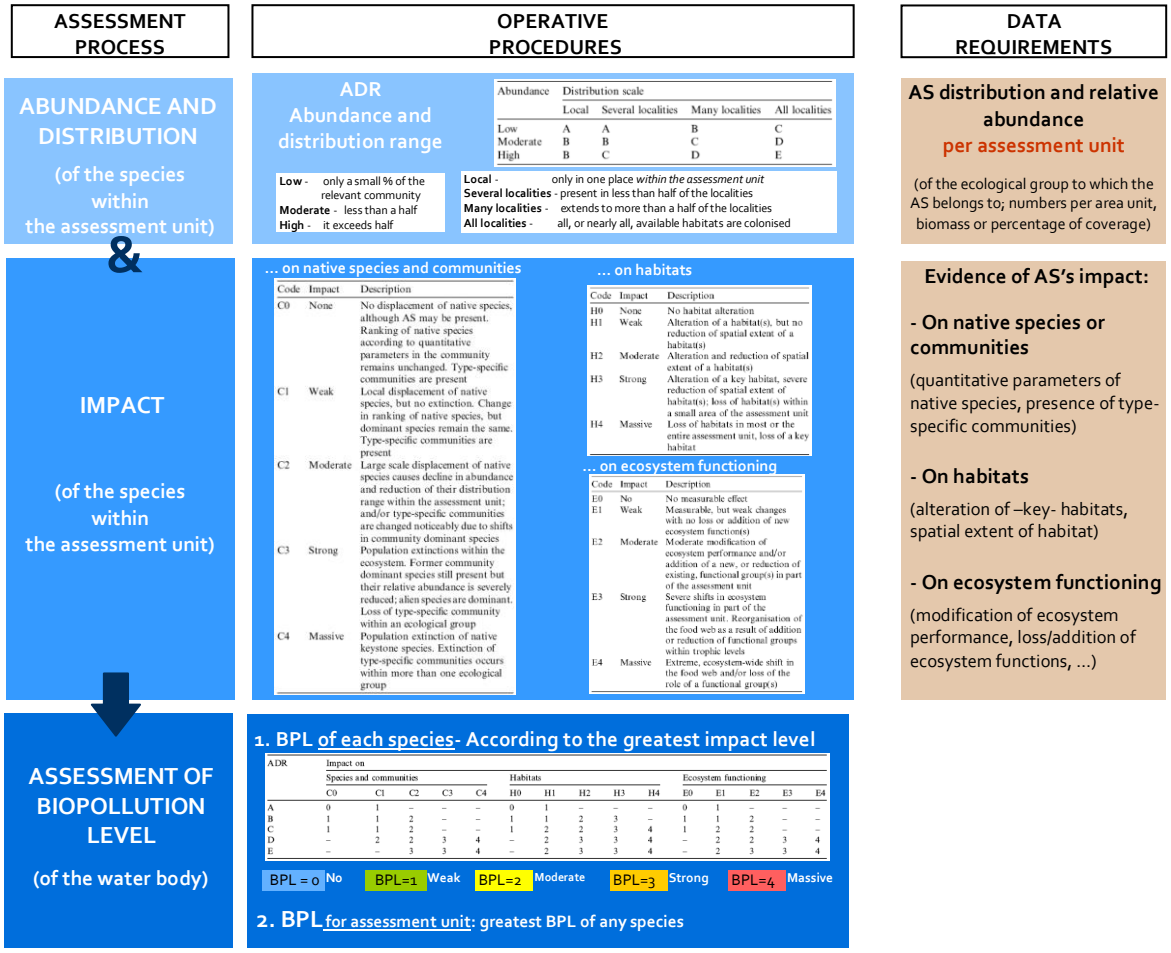
c. Biopollution level index (BPL), the (too?) perfect assessment of state

If the purpose of assessing biopollution is to understand changes in ecological quality associated with bioinvasions, a precise recognition of the real effects of AS may be more advisable than the appraisal of their possible impacts. In this respect, Olenin et al. (2007) proposed a method able to make an explicit account of AS abundance and distribution ranges, together with the actual impact of the AS on native species or communities, habitats or ecosystem functioning, based on scientific evidence. The evaluation procedure, shown in **Fig. 42**, provides a classification of water bodies along five levels from 'No' biopolution (BPL=0) to 'Massive' biopolution (SBC=5), which can be inversely associated with levels of biological quality according to the classification scheme of the WFD.

Later on, the method was also refined for its implementation to marine waters (Olenin et al., 2011, 2010). A system to facilitate the BPL calculation and information-sharing based on an on-line platform was designed by (Narščius et al., (2012). This method has been applied in several cases, mostly associated with estuarine or coastal areas in the Baltic using macroinvertebrates of phytoplankton (Olenina et al., 2010; Wittfoth and Zettler, 2013; Zaiko et al., 2011). As mentioned in **Section 1.2.1**, a test of the biopollution levels of coastal areas of Catalonia was also undertaken by Ballesteros et al. (2010: 90-97). The researchers using this method admit that it requires substantial research effort, although praise its usefulness for interregional comparisons and the evaluation of effects of individual AS (Zaiko et al., 2011).

Fig. 42 Procedure for the determination of biopollution level (BPL)

Source: Own elaboration based on Olenin et al. (2007)



A priori, the BPL index has excellent properties to grasp the condition of the water bodies regarding biopollution. However, there are difficulties to implement BPL for the case of fish in rivers of Catalonia, for the following reasons:

- Lack of detailed information about the abundance, ranges of distribution and effects of the species within each one of the water bodies. In particular, in the case of fish, the distribution and mobility within the water bodies are poorly studied.
- There is scientific reluctance to assert impact of fish species *in situ*, due to the high complexity of the aquatic ecosystems and the number of different stressors involved besides the presence of AS themselves.
- From the management point of view, the large amount of effort and resources needed to increasing knowledge about local distribution and actual impacts of high-risk AI may be better allocated in preventing the degradation of the state that in confirming that degradation *ex post*.

In sum, in Catalonia BPL could be applied to certain water bodies with presence of specific AS where research can provide reliable information. That is the case, for instance, of the assessment of biopollution in coastal areas, where the team of researchers in charge have accumulated primary data for decades. In general, that is not the case of fish in river ecosystems and data requirements for this method largely exceed the current state of data availability. If, in the future, knowledge improves, the BPL is a good candidate indicator for a precise evaluation of the state in relation to biopollution.

d. Comparison of methods and use of results

To conclude the test of applicability of these methodologies for the assessment of BC&BC, this section elaborates on the use of results and compares the results of the two indices that have been calculated, using the date for 2007-2008, estimated with biomass as indicator of abundance.

There is 82 percent coincidence in the results between SBC and IBPR. Discrepancies are related to water bodies where there is low abundance of black-list species (with results tending less favourable using IBPR) or areas with high richness of white-list species (with more favourable results using IBPR). In *ca* 5.1 percent of the water bodies, this discrepancy leads to a totally different signal in terms of the assessment and compliance (in terms of terms of achievement of good status) is dependent on the evaluation method chosen.

Table 44

Comparison of results SBC and IBPR levels (2007-2008, abundance as biomass), n_{WB2008}=235

Source: Own elaboration

Percentage of water bodies according to 'compliance'		IBPR	
		Compliance (0,1)	Non compliance (2,3,4)
SBC	Compliance (0,1)	53.2	0.0
	Non compliance (2,3,4)	5 .1	41.7

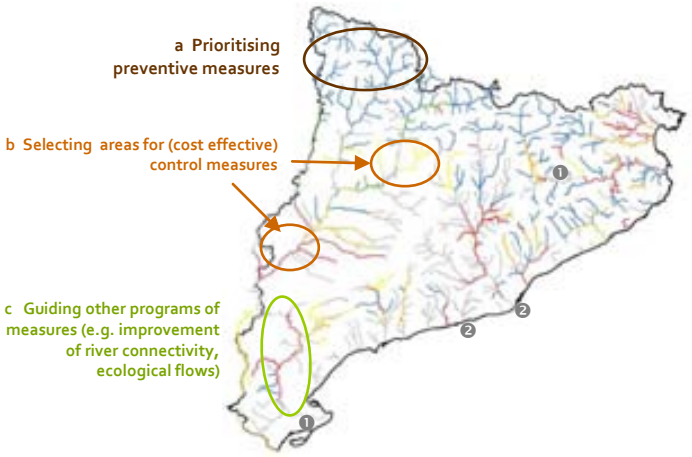
Type or results	SBC	IBPR	N_{WB}	%
Same result	0	0	125	53,2
	3	3	18	7.7
	4	4	49	20.9
Different result, same signal	2	3	1	0.4
	3	2	5	2.1
	3	4	6	2.6
	4	2	11	4.7
	4	3	8	3.4
Different signal	2	1	1	0.4
	3	1	11	4.7

In relation to the possible use of results, BP&BC can be helpful in several ways. **Fig. 43**, plotting the results of IBPR, will be used as an illustration. First, the identification of areas with low levels of biocontamination or risk of biopollution supports the development of preventive measures, at it is clear that that these areas must remain as priority zones for conservation of native species (for instance, the area 'a' in the map). Second, the allocation of available resources can be guided by a cost-effectiveness principle, employing them in areas where the biopollution risk is still moderate or low, instead of where it is severe, and therefore the intervention may result in a future situation of compliance (e.g., the choice between areas 'b' in the map). Third, BP&BC assessment can support programmes of measures with effects in the biotic communities. Thus, for example the improvement of river connectivity or the implementation of ecological flows, put in place in order to recover the hydro-morphological quality of the river, may have also adverse effects in relation to alien species, facilitating their spread to area where they were previously absent. The planning of such measures may take into account likely effects in BP&BC as one of the criteria for intervention.

Fig. 43 Mapping biopollution risk (IBPR) in Catalonia, 2007

Note: ❶ Water bodies different than rivers; ❷ Rivers without fish (explanation in the text below)

Source: Own elaboration



Finally, it is worth mentioning the meaning of the grey areas in the map, which introduce different elements of uncertainty. On the one hand, there are sections of the river basin that are not typified as rivers but fall under other categories of water bodies (wetlands, lakes, etc.). Therefore, the monitoring routine for rivers does not include them and there is not available information with the same level of detail than the river sections. Two examples are indicated with the sign ❶ in the map: the mouth of the Ebro River, considered a wetland, and the series of reservoirs in the mid-course of the Ter River that have appeared in previous chapters, considered as heavily modified water bodies.

On the other hand, there are actual river sections that where monitored but, for different reasons, no fish were caught. Two examples are indicated in the map with the sign ❷. In some of these areas, as in the many ephemeral streams along the coastal areas, the Mediterranean natural regime prevents the establishment of fish communities and the absence of fish is not surprising. However, in other areas, as in the mouth of the Llobregat River, the absence of fish indicates poor water quality. It might happen in the future that, due to river management practices, the physicochemical quality of the river improves to the extent that fish communities can be sustained there. In that situation, alien species that tolerate better poor water quality are likely to establish first. Oddly enough in this case the BP&BC indices would point to a worsening of the situation.

4.2.3 Are the BP&BC indices good 'state' indicators?

As indicated at the beginning of this **Section 4.2**, a clear association between stressors and the indicator used for quality status is considered a necessary property for the identification of suitable candidates to be state indicators. Then, a pertinent question would be whether the BC&BP levels are correlated with the gradient of pressure in the water bodies.

Anthropogenic activities or actions that may have an impact on ecosystem health are considered to be pressures (Conrad, 1979). In order to characterise the pressures in the sampling sites, the values of a stressor gradient assessment proposed by Munné and Prat (2009) were obtained, with permission , from the watershed authority for the different water bodies in Catalonia. This stressor gradient synthesizes the combined effect of different pressures, such as land use types and several types of contamination sources, together with the dilution capacity of the river ecosystem. The stressor gradient value (RI_AP) was available for the year 2003 for water bodies matching 246 sites in with available data on BP&BC in 2003 and 235 sites in 2007.

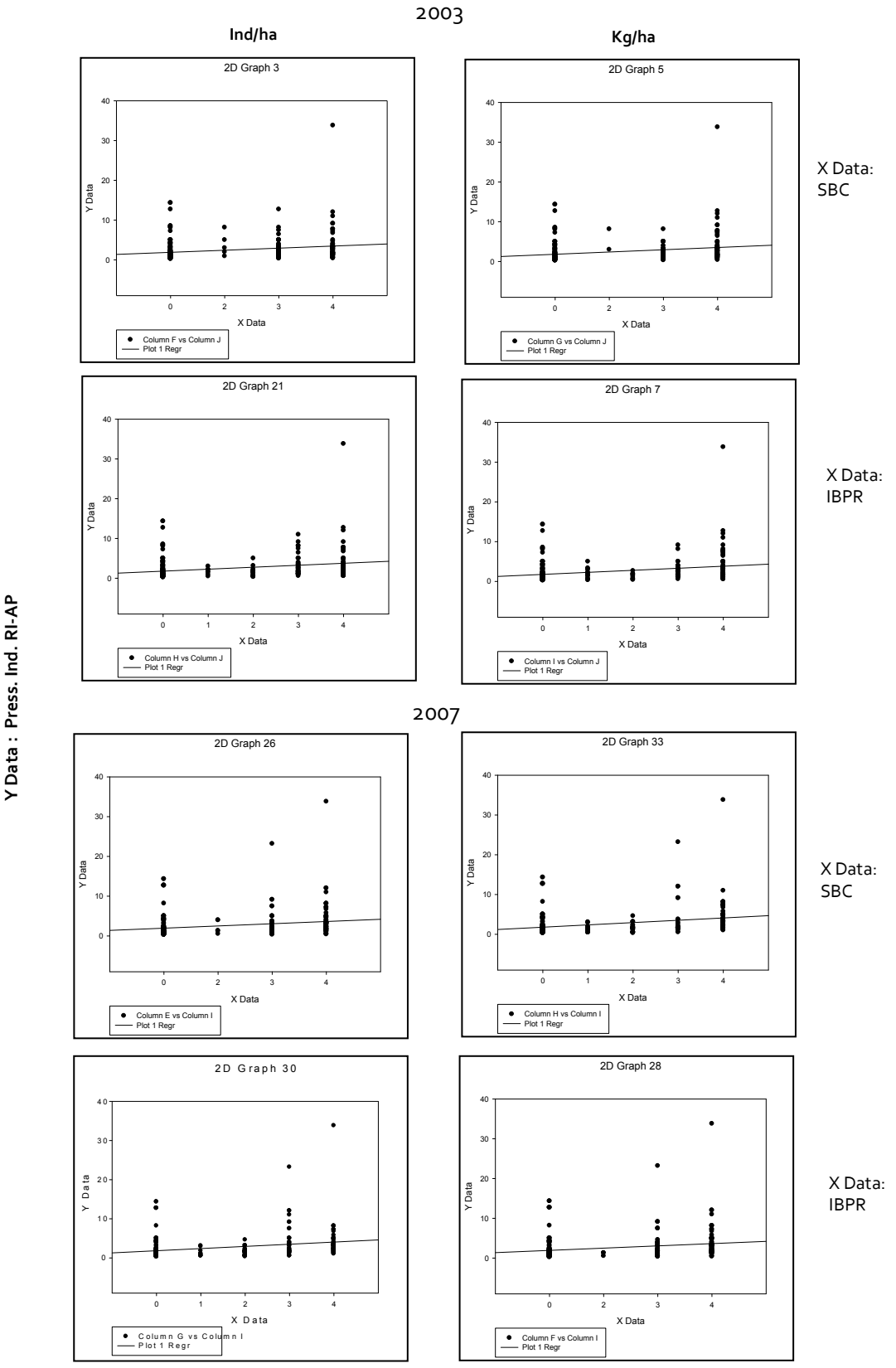


Fig. 44 Scatter plot of stressor gradient across SBC and IBPR levels
Source: Own elaboration based on SBC and IBPR (own calculation) and data on stressor gradient (by ACA)

The scatter plotting of the BP&BC levels and the stressor indicator (**Fig. 44**) pointed to a certain association of the variables: the higher the stressor value, the highest the BC&BP levels. Some visible outliers were confirmed not to be errors and therefore they were not excluded from the data set.

Then using a simple bivariate correlation analysis, which indicates how variables or rank orders are related, weak positive linear associations were found between BP&BC and the pressures in the water body. Similar results were found computing the correlations – based on the consideration of BP&BC indicators as ordinal variables – using two nonparametric correlation measures: Spearman's rho and Kendall's tau-b, run with Statistical Package for the Social Sciences (IBM SPSS version 21.0) (**Table 45**). There is a statistically significant correlation between both SBC and IBPR and the pressure indicators both in 2003 and 2007, with coefficients ranging from 0.215-0.315 [2003] and 0.208-0.313 [2007]. For both periods, the IBPR levels were slightly more correlated with the pressure indicator RI_AP than the SBC levels, regardless the indicator of fish abundance used (density or biomass).

The use of the Pearson correlation coefficient was also tested and it pointed out the same result, although the results are not included in the dissertation as this coefficient is admittedly more appropriate for scale variables.

Table 45

PB&BC levels and pressures, results of the correlation analysis

Note: **. Correlation is significant at the 0.01 level (2-tailed).

Source: Own elaboration. Full results in **Annex VI**

Test			RI_AP (BP&BC 2003)	RI_AP (BP&BC 2007)
Kendall's tau_b	SBCindha	Correlation Coefficient	.215**	.219**
		Sig. (2-tailed)	.000	.000
		N	246	235
	SBCkgha	Correlation Coefficient	.240**	.208**
		Sig. (2-tailed)	.000	.000
		N	246	235
	IBPRindha	Correlation Coefficient	.243**	.224**
		Sig. (2-tailed)	.000	.000
		N	246	235
	IBPRkgha	Correlation Coefficient	.240**	.239**
		Sig. (2-tailed)	.000	.000
		N	246	235
	RIAP	Correlation Coefficient	1.000	1.000
		Sig. (2-tailed)	.	.
		N	295	311
Spearman's rho	SBCindha	Correlation Coefficient	.274**	.282**
		Sig. (2-tailed)	.000	.000
		N	246	235
	SBCkgha	Correlation Coefficient	.305**	.271**
		Sig. (2-tailed)	.000	.000
		N	246	235
	IBPRindha	Correlation Coefficient	.315**	.296**
		Sig. (2-tailed)	.000	.000
		N	246	235
	IBPRkgha	Correlation Coefficient	.310**	.313**
		Sig. (2-tailed)	.000	.000
		N	246	235
	RIAP	Correlation Coefficient	1.000	1.000
		Sig. (2-tailed)	.	.
		N	295	311

These results suggest that biopollution and biocontamination are indeed associated with the gradient of pressures to the water bodies, although the current data availability does not point to a very strong association. The knowledge on pressures is expected to improve over time. In case a more precise or

sensitive indicator of pressures pointed out to similar or more intense association, the result herein presented would be confirmed.

In any case, the results obtained tend to confirm that BC&BP indicators have conditions to be pressure indicators. Besides the utility that this has for the specific context of the implementation of the WFD, this test provides new insights for the consideration of BC&BP indicators in relation to their applicability as an indicator towards the 2020 targets for biodiversity in Europe. Find more on this discussion in EEA (2012).

4.2.4 Are the results of BP&BC redundant with the indicators of biological quality?

After the WFD, the biological quality of rivers is assessed according to different biological quality elements (BQE): aquatic flora, invertebrates and fish. In relation to the other BQE, fish tend to signal larger spatial and temporal scale processes. As fish are often at the top of the trophic chain, they are sensitive to influences in the rest of aquatic communities. Moreover, fish have relatively higher social visibility and economic relevance than other BQE (ACA, 2006a). Being a part of popular culture and traditional ecological knowledge (e.g. Boquera Margalef and Quiroga Raimundez, 2001), changes in fish communities can be traced through historical and ethnographic research.

All the above reasons make fish a good base for assessing biological quality. Among the different methodologies developed in this respect, the indices of biotic integrity based on Karr (1987, 1981) have become widely accepted. This conceptual approach assesses the composition and diversity of species, their abundance and the conditions of the fish. In Catalonia, the index based on this approach, first developed in 2003 (Sostoa et al., 2003) and further refined in 2010 (Sostoa et al., 2010) is called IBICAT. It was commissioned by the watershed authority that uses it for guiding water quality assessment in rivers, together with indicators for the other BQE (ACA, 2006a). The index allows generating different quality levels based on the score for the different metrics included.

The process to refine IBICAT took particular care of the issue of alien species during the stage of selecting candidate metrics to be part of the assessment. Then, it is a pertinent question whether the results of this index in relation to the issue of AS made it redundant the calculation of an *ad hoc* BP&PC indicator as the ones that have been tested in this section.

In order to compare both types of information, data on the scores (from 1 to 5) for two different versions of the index ($IBICAT_{2010}$ [n_{WB}=234], $IBICAT_{2b}$ [n_{WB}=235]) was obtained, with permission of the watershed authority, for rivers in Catalonia. The data corresponds to the fish monitoring in the period 2007-2008, that is, the same raw data than the used for the calculation of the BP&BC indices of that period. Levels 1 and 2 correspond to very good and good quality level, and therefore, would point at water bodies in compliance with the WDF; levels 3,4 and 5 correspond to moderate, deficient and bad quality levels and would indicate incompliance with the WFD.

The results of the different quality levels for the both versions of the IBICAT index, compared with the corresponding level of BP&BC are shown in **Table 46**. The cells highlighted in light brown indicate the water bodies in which the assessment of biological integrity and BP&BC provide the same signal (either compliance or incompliance). Meanwhile, white cells indicate divergent results between these two kinds of assessment.

Table 46

Crosstabs of BC&BP levels and scores of the biological quality assessment for fish, frequencies, n_{WB}= 234, 235, period 2007-2008

Source: Own elaboration based on data provided by ACA

BC&BP level		IBICAT$_{2010}$ Score					IBICAT$_{2b}$ Score				
		1	2	3	4	5	1	2	3	4	5
SBC(ind/ha)	0	30	60	17	13	5	29	77	18	1	0
	2	0	1	1	1	0	0	1	0	2	0
	3	1	9	21	8	0	2	4	22	11	0
	4	0	1	13	34	19	1	2	11	40	14
SBC(Kg/ha)	0	30	60	17	13	5	29	77	18	1	0
	2	0	1	0	1	0	0	1	0	1	0
	3	1	8	23	8	0	3	4	22	11	0
	4	0	2	12	34	19	0	2	11	41	14
IBPR(ind/ha)	0	30	60	17	13	5	29	77	18	1	0
	1	0	3	4	0	0	1	2	4	0	0
	2	0	3	5	11	0	2	2	8	6	2
	3	1	4	16	9	3	0	2	16	15	0
	4	0	1	10	23	16	0	1	5	32	12
IBPR(kg/ha)	0	30	60	17	13	5	29	77	18	1	0
	1	0	5	6	1	0	3	2	5	2	0
	2	0	2	3	10	0	0	2	7	5	2
	3	1	3	13	9	1	0	1	13	13	0
	4	0	1	13	23	18	0	2	8	33	12

Based on this table of frequencies, it is possible to calculate the probability of coincident results and non-coincident result, shown in **Table 47(a)**. Looking at the different combinations of indices, it is clear that the probability of coincident results (ranging between 79-88 percent) is always higher than the probability of non coincident results (12-21 percent). Being the probability of coincident results remarkably high in both versions of the biological quality index, IBICAT$_{2b}$ seems to capture better the issue of BP&BC than IBICAT$_{2010}$ for each one of the indices and metrics used for the assessment of BP&BC.

Table 47 Coincidence of results between BC&BP levels and biological quality scores

Note: Compliance (C) means levels 0,1 for BC&BP and scores 1,2 for biotic integrity indicators; Non-compliance (NC) means is levels 2,3,4 for BC&BP and scores 3,4,5 for biotic integrity indicators

Source: Own calculation

a) Probability of coincident/non coincident results

BC&BP level		IBICAT2010 Score					IBICAT2b Score				
		1	2	3	4	5	1	2	3	4	5
SBC(ind/ha)	0										
	2										
	3	20 %		80 %			12 %		88 %		
	4										
SBC(Kg/ha)	0										
	2										
	3	20 %		80 %			12 %		88 %		
	4										
IBPR(ind/ha)	0										
	1										
	2										
	3	21 %		79 %			13%		87%		
	4										
IBPR(kg/ha)	0										
	1										
	2										
	3	21%		79%			13%		87%		
	4										

b) Conditional probability of non-coincident results

BC&BP level		IBICAT2010 Score		IBICAT2b Score	
		C	NC	C	NC
SBC(ind/ha)	C		28 %		15 %
	NC	12 %		9 %	
SBC(Kg/ha)	C		28 %		15 %
	NC	12 %		9 %	
IBPR(ind/ha)	C		30%		17 %
	NC	9 %		6 %	
IBPR(kg/ha)	C		30%		19 %
	NC	7 %		4 %	

Focussing now briefly on the non-coincident results, two situations are possible: that BP&BC indices indicate compliance while there biological quality index indicates incompliance, or the other way around. The first situation may be explained by the fact that the fish community suffers from a pressure unrelated to the issue of alien species. The second situation is more problematic from the point of view of the topic addressed in this dissertation. If the biological quality index indicates compliance, there would not be any signal for the water managers to engage in policy measures of ecological improvement, as the state of the water body would be considered as good or very good from the point of view of the fish communities. However, the BP&BC indices would be pointing out at the existence of a problem of bioinvasions in that particular water body.

With this in mind, the conditional probability of these two situations was estimated for the different indicators involved (**Table 47 [b]**). Conditional probabilities there are calculated according to the formula $P(A|B) = P(A \cap B)/P(B)$ when $P(B) > 0$, where the event of interest A is either the biological quality indicator (BQI)'s non-compliance (NC) or compliance (C) and the restricted sample space B is the opposite result in BC&BP level. The results shown in the table indicate that the probability of BC&BP compliance and biotic integrity incompliance (highlighted in orange) ranges between 15-30 percent, and it is always higher than probability of BC&BP incompliance and biotic integrity compliance (highlighted in purple), ranging between 4-12%.

This later result is relevant, because demonstrates that the standard quality assessment fails to completely pinpoint the issue of alien species. While the probability that this happens is relatively low, the failure is systematic regardless the indicator used. Of course, the considerations on uncertainty about the BP&BC indices presented along this section should be taken into account when interpreting this result.

In any case, based on the results presented in this section, it can be argued that the biological quality index used for fish in Catalonia and the BP&BC indices are not redundant. While there is an undeniably high level of coincidence between their results, they do not reflect the same thing, and there is a small probability of systematic failure of the BQI to provide the required policy signals.

4.2.5. Concluding remarks about biopollution and biocontamination indices

The consideration of AS in the assessment of biological quality is necessary whenever there is evidence that AI constitute a pressure to or have an impact on the aquatic ecosystem. Some voices even claim that the high ecological status is unsuited for water bodies where AS are present. Yet taking up AS until the last consequences in ecological status assessment may be problematical for water managers. In Catalonia there are practically no water bodies without alien species present. The eradication of most of them is environmentally or economically unfeasible. Should a strict AS-based quality assessment be adopted, the water policies would be locked in the predicament of recognising a problem of generalised poor ecological status without being able to effectively redress this situation.

In this context, the existence of supplementary BP&BC indices is helpful to guide policies in support of increased biological quality. In the case of Catalonia, and using fish as biological element, two of the methodologies present in the literature can be estimated with the existing monitoring data and would not require further sampling effort beyond the routine monitoring.

The BP&BC indices thus estimated undoubtedly provide useful information for the management of AS in aquatic ecosystems. The classification of water bodies or, as a part of the calculation of IBPR, a classification of the AS themselves, helps to prioritize efforts, targeting those management units or species whose control will have the most benefit for the available resources. In the case of the species, such a classification could be easily linked to regulatory frames. For instance, it could be helpful to communicate to the general public why the possession, sale or any other kind of management is restricted for 'black species'.

In fact, impacts of the species are explicitly taken into account in two of the methodologies introduced, although in one case the impact is presumed based on the information from the literature and the other requires actual evaluation *in situ*. A consideration in relation to species' impacts is the extent to which the criteria for classification are discussed with stakeholders. Although the assessment itself must be guide a systematic organisation of knowledge, and therefore, can be considered as a scientific endeavour, an agreement with stakeholders on the reasons why a particular species is considered as a hazard will benefit both the comprehensiveness of the analysis and the use of its results in policy making.

In general, the indexes fall short of portraying species whose impacts are not completely understood. Additionally, an element that is absent from the different BP&BC indicators, and that it would be likely to emerge as a result of an open discussion about AS impacts and biopollution, is the recognition of the ambivalence of the species. From the ecological point of view, the potential benefits of alien species include providing habitat or food resources to rare species, serving as functional substitutes for extinct *taxa*, and providing desirable ecosystem functions (Schlaepfer et al., 2011). Moreover, many of the AS, as some of those present in Catalonia, are economically important. Despite this, there is such a scant research done on the potential conservation benefits of alien species that make it think that the topic is a scientific taboo. With increase knowledge about these potential benefits, a new challenge would rise on the best way to integrate it in BP&BC assessment: can benefits be an offset for negative effects of the species?

This section about biopollution closes with some final recommendations informed by the testing and analyses done. A major point here is that water bodies are not necessarily homogeneous in terms of the represented habitats, overall all in relation to flora species. A relative abundant species may cause diverse impact depending on the type of habitats along the water body. As a result, the attribution of the impact on habitats may differ. Therefore, a more precise assessment of biopollution, based on actual information about AS impacts, would benefit from changes in the monitoring protocols that involved data gathering about local distribution and effects on local ecosystems and biodiversity, even if it is under qualitative basis. Another point is the taxonomic groups to be included in the analysis. Due to data availability reasons, the assessment in this section has relied on fish species. As indicated above, most of the tests of biopollution and biocontamination have been done using macroinvertebrates. Potentially, the methodology can be used with any *taxa*. Then a question would be whether other types or organisms with very likely negative effects in ecological status (e.g., zoonotic organisms like parasites) should not be explicitly addressed outside the classical BQE including in the assessment of ecological state.

4.3 Scenario development in the assessment of biological invasions

Scenarios have been used as planning tools for over five decades in various areas (Kahn and Wiener, 1967; van Notten et al., 2003). In an attempt to summarise views, Berkhout and Hertin (2003:45) indicated that the benefits of scenario analysis and planning are twofold. First, the scenario approach expands the range of outcomes considered in strategic decision-making. It encourages new ways of thinking about the future and linking the different components and actors of a complex problem in the policy design process. Second, the process of scenario-making and elaboration is itself seen as a contribution to prepare the grounds for change, as scenarios challenge conventional wisdom and encourage debate. It is argued that juxtaposing scenarios provides a means to think about the relationships between choices, dynamics, and alternative futures (Gallopin et al., 1997b). Given their flexibility and promotion of links between science and social actors in complex issues, scenarios are part of the methodological toolkit of science-governance-policy interfaces in environmental matters, such as social multi-criteria evaluation (Kowalski et al., 2009; Stewart et al., 2013) and integrated assessment (Bohunovsky et al., 2010; Caille et al., 2007; Kasemir et al., 2003).

Scenarios have been employed to analyse the impact of different policies on global or regional sustainability, such as energy policies, climate change or EU enlargement (Rotmans et al., 2000; Wehrmeyer et al., 2003). On the global scale, for instance, the IPCC developed a set of scenarios illustrating the impact of specific developments in population growth, energy use and technology, and associated climate change patterns (IPCC, 2007; Rogelj et al., 2012). Other examples of global scenarios include the Global Scenario Group (GSG) scenarios (Bertrand et al., 1999) and World Water Vision Scenarios (Gallopin and Rijsberman, 2000). In Europe, the European Commission promoted a number of studies, including *Vision 2020* (EC-DGXI, 1996), *European Energy to 2020* (EC-DGXVII, 1996), *Scenarios Europe 2010* (Bertrand et al., 1999) and *Four Futures of Europe* (Mooij and Tang, 2003).

Scenario development for assessing biodiversity is an emergent application. Understanding of ecosystem change is addressed by considering the evolution of its drivers. Mainly focused on larger scales, both analytic and participatory methods have been employed for biodiversity-related scenario development. Related studies are presented in

Table 48, including one example dealing with invasive species. This case, together with the most recent work by Roura-Pascual et al. (2011), count among the very few implementations of scenario planning in the field of bioinvasions.

Both are related to plant invasions in South Africa and explicitly aim at guiding management options. Their conclusions point at the benefits of formulating management strategies based on scenarios. The reasons argued are that scenarios allow expanding the knowledge of the factors driving invasions in a context of multiple complexities and uncertainties in future environmental conditions. Without fully implementing a scenario approach, Albins and Hixon (2013) and Hellmann et al. (2008) also use scenario techniques and terminology to forecast future developments related with alien species with the aim of underpinning long-term management processes.

Table 48 Scenarios for biodiversity assessment

Source	Purpose	Type	Main scenarios
Global biodiversity (Sala et al., 2000)	To project changes of global biodiversity according to alternative evolution of driving forces.	Analytic / Model-based Quantitative models based on changes in driving forces and the known sensitivity of biodiversity to these changes.	*SUM*: No interaction among drivers *MAX*: Antagonistic interactions between drivers. Biodiversity respond only to the driver to which it is most sensitive *MULT*: Synergistic interactions between drivers. Biodiversity responds multiplicatively to drivers of change
Biological invasions in South Africa (Chapman et al., 2001; Le Maitre et al., 2004)	To anticipate and understand possible trajectories of plant invasions in South Africa in a frame of complexity	Analytic / Expert-based Qualitative storyline based on workshop activities with natural scientists	*Garden of Eden*: strongly performing economy and coherent policies and regulations. *Another farmyard*: strong national economy but weak regulatory environment *Green desert*: weak national economy and weak regulatory environment *New mosaic*: weak economy but strong regulatory environment
GEO-3 (UNEP, 2007, 2002)	To provide to decision-makers a picture of what tomorrow might bring in terms of human well-being and environmental security and what the impact of their decisions is likely to be.	Analytic / Hybrid (model-based – expert based) Qualitative narratives take centre stage with the quantitative tools playing a supporting role	*Markets First:* market-driven developments converge on the values and expectations that prevail in industrialized countries *Policy First:* strong actions are undertaken by governments in an attempt to reach specific social and environmental goals *Security First:* great disparities, where inequality and conflict prevail, brought about by socio-economic and environmental stresses *Sustainability First:* new development paradigm emerges in response to the challenge of sustainability, supported by new, more equitable values and institutions
Regional ecosystem services (Peterson et al., 2003)	To assess the sustainability of ecosystem services in a region in transition (Northern Highland Lake District, Wisconsin)	Participatory / Ecological scientist & stakeholders Qualitative narratives based on social and ecological processes that are known to take place	*Walleye Commons*: Development decrease and little effective lake management *Northwoods.com*: Development increase, moderate vulnerability, protection of certain lakes *Lake mosaic:* Development increase, management by groups of residents surrounding specific lakes
Global biodiversity loss (MA, 2005a)	To address the consequences of different plausible futures for global ecosystem services and human well-being	Analytic / Hybrid (expert based - model-based) Combination of qualitative storyline development based on interviews and literature review and quantitative modelling based on assumptions about the evolution of indirect drivers	*Global Orchestration*: global economic and social policies are the primary approach to sustainability *Order from Strength*: protection through boundaries becomes paramount *Adapting Mosaic*: environmentally proactive local and regional management as the primary approach to sustainability *TechnoGarden*: potential role of technology in providing or improving the provision of ecosystem services.
ALARM project (Settele et al., 2012; Spangenberg et al., 2012)	To explore possible future risks to biodiversity in Europe, stimulating interdisciplinary learning and policy awareness	Analytic / Hybrid (expert based - model-based) Qualitative narratives illustrated with several sectoral models (econometric, ecosystem, land use) , combined with outputs from climate models	*Business As Might Be Usual (BAMBU)*: known and foreseeable socio-economic and policy trajectories in EU decision making. *GRowth Applied Strategy (GRAS)*: liberal, growth-focused policy-driven scenario *Sustainable European Development Goal (SEDG)*: socially, environmentally and economically sustainable development.

Studying the factors that contribute to the introduction, establishment and kind of impacts of alien species, seems to enable the exploration of key uncertainties tied to the socioeconomic and institutional context of bioinvasions. Thus, decision making may be informed about the kind of social response and economic impact that may be expected from the implemented measures. With this in mind, two different approaches to scenario development are tested and reported in this section.

In the first case, local and regional stakeholders in the Ebro joined in a structured exercise of participatory scenario development which was the first implementation of such approach to the issue of aquatic bioinvasions. In the second case, analytic management scenarios were developed based on a detailed knowledge of the pre-invasion context in the Ter River.

Table 49 overviews some elements of interest in both cases, developed in greater detail along the following **sections 4.3** and **4.4**. Additionally, the use of scenarios to understand inter-scale interactions, and the role of agency (as defined in **section 2.3** above) is analysed in **section 4.5**.

Table 49 Approaches in the scenario development of aquatic invasions in two Catalan regions

Source: Own elaboration

Context	Approach	Type	Outcome	Expected support to IS management
Post invasion (Low Ebro River)	Crossover of key uncertainties	Participatory Qualitative	Qualitative narratives of the invasion	Deliberation
Pre invasion (reservoirs in the Ter River)	Alternative management options	Analytical Qualitative / quantitative illustration	Qualitative narratives of the invasion Management guidelines Estimated impacts	Deliberation Management guidelines

4.3.1 Scenarios post-invasion: zebra mussel and European catfish in the Ebro River

This section reports a practical experience of participatory scenario development carried out in the case of the Ebro River.[19] In 2005, several years after the detection of the zebra mussel in the Ebro River, the specific ways why and how the invasion was taking place, and how it was related with the presence of other alien species had not been openly discussed among the main stakeholders. At that time, zebra mussel was known to be established only in the original area of detection with signals of its spread to new nearby basins. In this context, it seemed clear to the author that the information from the developments in that region was crucially relevant both for the organisation of a local response and for the preparation of preventive measures in other neighbouring areas. That motivated the organisation of a participatory scenario exercise, the results and insights of which are presented next.

[19] With acknowledgement to the financial support of European Integrated Project ALARM (COCE-CT-2003-506675) and the training action Marie Curie in the University of Leeds. The very active role of Rosa Binimelis and Iliana Monterroso in the organisation of the workshop is also gratefully acknowledged, as it is the logistic support by Grup de Natura Freixe in Flix. The contents of this section were previously reported in my master dissertation '*Interlinked biological invasions in the Ebro River. A multi-scale scenario approach*'.

4.3.1.a Methods and participants' selection

The **methods** encompassed three stages, which extended along four months: preparatory activities, the conduction of a participatory workshop and the assessment of results through desk research.

The preparatory activities started from the preliminary contacts with stakeholders and formal invitation. Prior to the workshop, a series of interviews sounded out stakeholders' opinion about the utility of a participatory scenario development. This permitted the adaptation of the agenda to the participants' expectations, which was specified in the formal invitation. As a part of the preparation, the necessary facilitation resources were designed (participants' kits, reporting templates and a presentation for conducting the workshop).

A full-day scenario workshop took place in the facilities of the Sebes Natural Reserve, at Flix, on September 22nd, 2005. The workshop aimed at promoting deliberation among the participants around management scenarios of biological invasions. To this end, a group dynamics was conducted adapting the methodology of the IDON Scenario Thinking (Galt et al., 1997). The exercise encompassed several roundtables, assemblies and leisure breaks (see **Annex VII**). During the breaks exchange about the evolution of the workshop was also promoted. The dialogue was kept in Catalan and Spanish, depending on the preference of the participants. The records of the exercise comprise the filled templates, photographs and both audio and written records.

Finally, the scenarios were assessed through desk analysis. This phase included the assessment of both results and methodological process. Participants' opinions and ex-post appraisals (e. g. emission of local radio reports) were taken as inputs for the assessment.

Fig. 45

Diverse moments during the scenario workshop

Source: ALARM-UAB team

The phase of **participants' selection** made clear that many of the stakeholders had a role in both invasion processes (zebra mussel and Wels catfish). In part, this is due to the fact that both invasions were taking place in the same geographic area. Moreover, already in the preliminary contacts the interrelation of both invasions was pointed out by several interviewees. Therefore the decision was to undertake a joint exercise of scenario development for both species.

With this in mind, criteria for selecting the participants needed for the workshop were: a) representation of the different groups of stakeholders identified during the institutional analysis; and b) decision-making capacity at the local level. Eighteen stakeholders from fifteen organisations participated in the exercise (**Table 50**). Additionally, some stakeholders confirmed their participation but did not attend for several reasons. They are presented for transparency and also because their absence generated some reactions from the participants that were reflected in the storylines.

Table 50

Selected participants of the scenario workshop

Source: Own elaboration

Selected stakeholders	Sector	Organisation
Participants in workshop	Regional administrations	DGA, Servicio provincial de MA en Zaragoza
	Municipalities	Ayuntamiento de Mequinenza
		Ayuntamiento de de Flix
	Watershed authority	Confederación Hidrográfica del Ebro (Quality Area)
	Chemical industry	Erkimia (Area waste waters treatment)
	Tourist sector	Badía Tucana
		Club nàutic de Riba-roja
		Industria hotelera (Hotel hacienda Pepito)
	Angling societies	Societat de Pescadors "El lucio" de Flix
		Societat de pesca 'la carpa' Riba-roja
	Environmental organizations	Grup de Natura Freixe
		Pla de Protecció Integral del Delte de l'Ebre – COCE
	Universities	Universitat de Barcelona
		Universitat de Lleida
		Universitat de Girona
Non-attendant stakeholders	Electric company	ENDESA / ENHER
	Regional administrations	Generalitat de Catalunya, Dir. General de Medi Natural
	Municipalities	Ayuntamiento de Riba-roja
		Ayuntamiento de la Pobla de Massaluca

4.3.2.b Results

An important component of the employed methodology is the facilitation of stakeholders' reflection by means of visual language in every step of the dynamics, including: 1) Identification of driving forces; 2) Hierarchy of driving forces, 3) Identification of key underlying themes; 4) Generation of scenarios and 5) Development of storylines. **Section 2.2** reports the results of the two fist stages of the exercise related to the identification and classification of driving forces. What follows is the use that the participants made of such hierarchies to complete the scenario development.

- *Identification of key underlying themes*

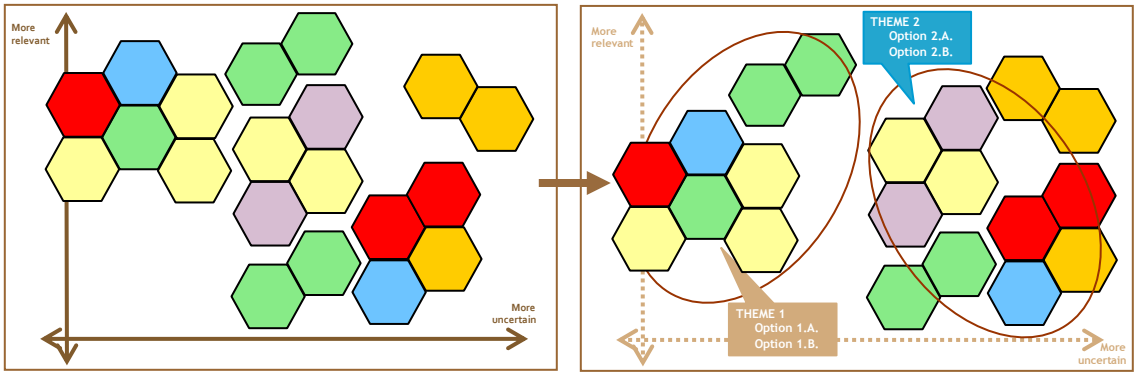
Disclosing perception about the relevance and the controllability of the driving forces focuses the analysis in those important factors whose evolution is not predetermined. A thematic cluster of such factors allows recognizing the critical uncertainties, key themes whose alternative evolution underlies the progress of biological invasions.

Those topics considered as key themes were water use management and the character of administrative framework. The first one included all these factors related to the specific economic practices using water resources. This comprises irrigation, domestic consumption, energy production

and, very especially, recreation activities. The second one refers to the nature of the administrative response to the invasion. It involves elements as institutional responsibility, mechanisms for control and inspection, normative performance and prevention culture, among others.

Fig. 46 Identifying key uncertainties

Source: Own elaboration.



- *Generation of scenarios*

Each one of the key underlying themes or key uncertainties evolves according to a non determined rationale. Next step of the scenario development is unveiling possible rationales. The alternative should not be the identification of the both 'good' and 'bad' options, but abstracting the practical choice based on stakeholders' knowledge about the critical uncertainties.

Labelling the options for the two underlying themes is a way to summarize the general view. In the case study, the group of participants recognized the alternatives presented in **Fig. 47**.

Fig. 47

Identified options for key uncertainties

Source: Own elaboration

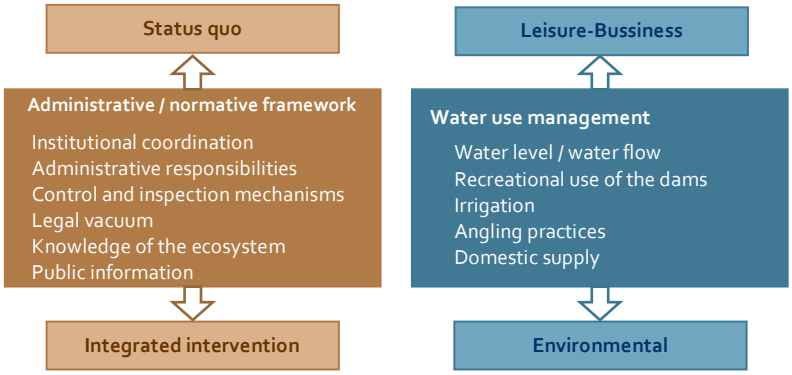


Fig. 48

Generation of scenarios from key uncertainties

Source: Own elaboration

		Administrative / normative framework	
		Status quo (*Statu quo*)	Integrated intervention (*Intervención integrada*)
Water use management	Leisure / Bussiness (*Ocio / Negocio*)	SCENARIO I	SCENARIO II
	Environmental (*Ambiental*)	SCENARIO III	SCENARIO IV

The stakeholders distinguished an administrative / normative framework where the institutional lack of coordination prevails (*Status quo*) versus another where the intervention is organized under common purposes (*Integrated intervention*). On the other hand, the water use management can be guided by the demand made by different economic actors (*Leisure – business*) or a more ecosystem-based management is carried out (*Environmental*). The combination of each alternative for both key themes allows generating the niches for the scenarios to be described, as it is shown in **Fig. 48**.

- *Development of storylines*

Once identified, the scenarios must be filled with contents. A fist step for this is titling each scenario. This generates a fundamental frame to focus the discussion. Contents are provided by joint deliberation about the plausible evolution of each driver under the specified option for their correspondent key theme. This way, storylines are built up. Narratives synthesizing stakeholders' contribution are presented in **Box 5**.

In the first scenario, *Every Man for Himself*, there is a strong utilitarian focus on the water use management in the Ebro. The second scenario, *Politically Correct Business*, depicts a river management centred on recreational market-based activities developing in a coordinated administrative context. *Administrative Chaos with Good Intentions* describes an Ebro wherein an environment-friendly normative is implemented without cooperation between administrations and other stakeholders. In the fourth scenario, *Shangri-la*, an ecosystem management of the river is attempted together with an effort of integrated action between stakeholders.

Box 5 Four participatory scenarios of bioinvasions in the Ebro River

Scenario I. Every man for himself! (*Campi qui pugui!*)

Lack of coordination emphasizes individualism as the utilitarian focus of water use management. In this scenario there is a strong weight of the economic interests in the exploitation of resources, above all recreational activities around sport angling. Visits of international anglers and traffic of boats increase as also revenues from fishing licenses and angling related business. Sales of bait, including living bait, rise. Other uses of water, as domestic consumption and irrigation, increase their demand.

As a result of the intensification of their driving forces, both invasions spread. Zebra mussel continues causing damages and spreads to other basins. Administration does not play an active role in the management of the invasion processes. Different local and regional authorities exercise diverse administrative roles without coordination. Lack of effort is reflected in the persistence of legal gaps. As a result of the lack of resources for control and inspection, non-compliance of both navigation and fishing rules remain, as well as the non-controlled use of jetties.

'Easy solutions' are adopted for controlling the invasions, like chemical and biological control by the introduction of other exotic species. Deliberate introductions of exotic fishes are used as well for maintaining the critical mass of fishable species. Local ecosystems are strongly affected.

Scenario II. Politically correct business (*Negoci politicament correcte*)

In this scenario both business and marked-based activities for leisure prevail in the context of an integrated administrative performance. Management is subordinated to political will, which eventually decides the chosen direction. There is a common goal that may be pursued by different stakeholders.

Integrated intervention overcomes some of the drawbacks. Thus, for instance, sharing available resources for inspection and control reduces the problem of their scarcity. Policy is oriented to good environmental practices. One of its branches is environmental education, which promotes general knowledge of local ecosystems through programs of environmental communication. Scientific knowledge of the invasion processes is enhanced by research activities.

These innovative elements for controlling the invaders take place together with the pre-eminence of utilitarian values for the water management. For instance, legal framework protects recreational activities, relaxing administrative mechanisms for this sector. Well-organized installation of facilities (e.g. jetties) is promoted, as well as diversification of the tourist activities developed in the area. Good tourist practices include the definition of confined areas for angling.

There is flexibility to avoid those non-controlled tourism activities that contribute to the spread of the species. Regulations meet real needs thanks to the cooperation between economic actors and rulers. Political action is, in this sense, agreed with social stakeholders.

Scenario III. Administrative chaos with good intentions (*Caos administratiu amb bones intencions*)

An environment friendly normative framework is developed, but its implementation is applied in the context of passive lack of cooperation between administrations and stakeholders. Regulation of water uses for controlling the species exists, although it is not specific enough and it is complied only occasionally. Policies for public awareness (as informative campaigns and signalling) are not specific enough.

Economic agents bear the costs of the zebra mussel pest. This includes preventive mechanisms like filtering systems and alternative intakes for human consumption (e.g. digging wells). Concurrently, a deliberate self-restriction of water demand is carried out by some sectors, for instance agriculture.

Ecotourism activities exploit other alternatives aside the water use (e.g. landscape visits, trekking). This gives a boost to sustainable tourism, including angling practices. Thus, for instance, use living bait is restricted. For this reason, the speed of the species spread is somewhat reduced. Specific management actions in this regard are:

- river surveillance and monitoring of the pest evolution;

- managing the level of the reservoirs and controlling floods for avoiding the spread of the species;

- preventive measures for the new village water intakes, as well as the protection of the current water intake systems.

Lack of orchestration affects not only the administrations but also other actors including scientific research. Without coordination, different studies focus on different aspects of the problem.

Scenario VI. Shangri-la (*Shangri-la*)

Shangri-la scenario is fruitful from the point of view of controlling invasive species since administrative and normative issues are properly ruled. In this scenario, the integrated action of different administrations and groups of stakeholders contributes to the accomplishment of agreed laws. Better implementation of norms is combined with an increased information flow, especially that coming from scientific research. Information exchange gives a boost to better management.

At the level of uses of the reservoirs, activities and responsibilities are allocated in a transparent way. A real control arises from the shared guardianship of the resources. This way, certifications and quotas are complied with. Social context is also important to support the assumption of a better accomplishment of the legislation. Each economic sector is subject to a specific performance line.

Specific management instruments accompanying this scenario are:

- Promotion of information flow and development of environmental education programs

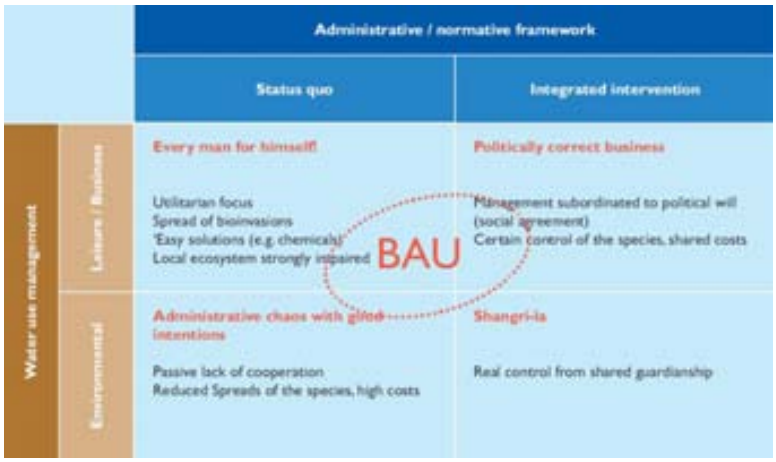
- Promotion of scientific research

- System of routine inspections
- System of cleaning certificates
- Territorial planning of different activities employing the river

An additional scenario would characterize the 'Business as Usual (BAU)' situation. Since administrations are organized to a certain extent, and environmental interests influence some of the management practices, BAU would be in the middle, leaning towards lack of coordination and utilitarian management.

Fig. 49 Scenarios in the Ebro River, including BAU

Source: Rodríguez-Labajos et al, (2010)



4.3.2.c Assessment of scenarios by stakeholders and perceived usefulness

Development of scenarios by stakeholders plays as a test for its consistency. Self-assessment reinforces this consistency. Next, participants' opinions about scenarios are summarised.

- ***Campi qui pugui***. For local stakeholders, this is not a realistic scenario. Apparently, it is a very negative scenario that might be employed as base line or business as usual scenario. However, participants did not agree in likening this scenario with current situation. They recognized that control actions were already taken into account. As example, the distinction between legal and illegal jetties and the inspections of fishing permits is mentioned.
- ***Negoci políticament correcte***. This is perceived as a better scenario than the existing situation, since there is a common objective that can be pursued by all the actors. Local stakeholders, especially those related to economic activities, highlighted their prime interest in preserving local resources as a means to keep their activities working. Placing policies at the service of business and consensus are key factors that would contribute to social agreements.
- ***Caos administratiu amb bones intencions***. Lack of coordination characterizes this scenario. This is found as a main pitfall for any management initiative. Stakeholders adduced that, in spite of the environmental inclination of watershed management, lack of coordination between stakeholders would avoid suitable performances. Thus, failures to comply with the law would prevail. Disarray would extend to scientific research, turning out to be incomplete and disperse.

- ***Shangri-la***. This scenario is perceived as a utopia and less real scenario. For the participants, the presented context is crucially dependent on political will. A factor perceived as particularly hard to reach is the real coordination between the administrations. According to stakeholders' perception, administrative performance is not driven by local needs but by external political interests. The fact that different political parties rule the diverse local and regional administrations is regarded as a barrier to coordination.

Besides assessing each scenario, stakeholders also made relevant observations about the desirable dynamics. While there is consensus in avoiding '*Campi qui pugui*'' as future evolution, the opposite image 'Shangri-la' was not necessarily the favourite scenario. Stakeholders wanted to move forward to a context where agreements are easier to reach. In this sense '*Negoci políticament correcte*' was praised. The opinion was that the good utilitarian management is not incompatible with environmental considerations as long as it is properly governed. Meanwhile, '*Shangri-la*', and '*Caos administratiu amb bones intencions*' would lead to conflicts, which local stakeholders seemed to avoid.

In relation to the usefulness of the scenarios for the stakeholders, and particularly, for the management of the invasion, four main axis are explained next.

- *Framing local situations in the larger underlying influences*

Local actors aim to keep their livelihoods in the frame of successive rounds of historical subordination to external interests and strong (and successful) reaction against them. In this sense, both biological invasions and policies for protecting biodiversity can be interpreted as a new round of external impositions. As they have done historically, local stakeholders will adapt to them. Through the development of scenarios, stakeholders could share their views in the problem definition, and framed their local concerns in the larger underlying dynamics. In this way, two elements were promoted: support to shared responsibility and a contribution to empowerment (based on an extended knowledge of the processes).

But adaptation is not the only – and for other topics, most prevalent – way of interaction with the larger-scale dynamics. Reaction is also an important strategy (as developed further in **section 4.3.5)**.

Specifically, each participant could: a) recognise factors driving the invasion process according to his or her own views and other stakeholders' perspectives; b) define relevant key uncertainties of the cases; c) identify criteria for the assessment and d) include the obtained information in their decisions of adaptation or reaction.

- *Accompanying social learning and participation*

Development of scenarios by means of participatory techniques entailed the interaction of the analyst with the object of study. While generally this is accepted as a risk for the objectivity of scientific work, it also allows a reconfiguration of the knowledge domain for both the researcher and the participants.

During the interaction process, the purpose of each stage was presented in order to enhance transparency. In this way, participants shared their points of view in a structured way. Many possibilities arose for recognizing the implications of every contribution in the frame of the shared vision of the problem. Some topics generated interaction between stakeholders with asymmetric

knowledge. Two-way communication boosted learning focussed on specific topics around the invasion process. As example, the following matters can be mentioned:

- Different meanings of water quality (biological quality, quality for human consumption) and their correspondence with the selected indicators.
- The current distribution of the species. Some actors ignored the recent invasion of the Mequinenza reservoir, a definitive sign of the spread of the invasion upriver.
- Changes in the fishing law and the potential effects in terms of loss in local guardianship of river resources. Linked to this, stakeholders gave examples of previous effective agreements between administrations that disappear after political changes.
- Actions being carried out by the authorities (beyond the generalized opinion that they do not work in a coordinated way).

- *Guiding management?*

Organization of local initiatives around common positions would have been a desirable result of scenario development. In this regard, focus on common specific issues was more valued than the dispersion of initiatives around ambitious environmental plans. What is the obstacle to this organization in the case of invasions? This is restricted by the existence of asymmetries of power regarding decision-making capabilities (either financial or administratively based).

In addition, both case studies offer elements for consideration regarding scenario development.

a) Zebra mussel.

All the stakeholders agreed in considering the species as an unwanted organism, through recognizing its opportunistic usefulness against the Ebro River water transfer plan. The kind of response that should be adopted is not that clear. They desire to come back to the state prior to the introduction, when no zebra mussel was present in the river. However, this was not a part of any of the described scenarios. Stakeholders acknowledge a lack of options for the eradication of the species. Even the most radical solution (emptying the reservoirs) did not seem to be completely effective and loss any plausibility after the discovery of the species upstream the reservoirs. No agreed decision and partial responses had been the reactions observed by the stakeholders.

Taking this into account, scenarios are a good frame for developing adaptation strategies in the area affected by the pest. Additionally, the described elements are keys for detecting areas in Spain and perhaps elsewhere (the IBC, Portugal, Morocco) prone to be invaded in the future, where prevention is still possible. This links to the development of scenarios pre-invasion, as it is shown in **section 4.3.4**.

b) Wels catfish.

In this case, the course of action is not clear. Economic benefits of the invasion seem to overcome its ecological impacts. Environmentally motivated agents are not strong. They lack veto power. Legislation points out to the control of the species by means of the systematic sacrifice of the catches. Anglers refuse this action due to sportive and ethical reasons. But the workshop revealed the strong belief that the presence of the species has been and still is a driver of the invasion of zebra mussel.

Interlinked invasions means interlinked responses, and they are better addressed if management employs integrative assessment methods, like scenario development.

- *Providing the grounds for larger scale management [a postscript]*

Soon after the results of the scenario exercise presented in this section were reported by Rodríguez-Labajos (2006), evidence of a considerable spread of the zebra mussel along different parts of the Ebro Basin triggered changes in management for the different regions involved. In Catalonia, control measures were passed by the authorities in charge of natural environment to the water management authority, ACA. The author of this thesis was invited to coordinate this process with freedom to integrate the research results within the new management scheme.

This happened in the context of an emergency situation, with public attention focused on the governmental response to an issue that for a period became high-profile. While the link between the measures implemented then and the research results were not explicitly stated, some key aspects were actually integrated. In order to prevent the spread of the invasion to the non-affected areas, there was a focus on the dispersal pathways.

Control of fish restocking, restrictions to boat traffic and the development of a boat disinfection system, in line with the recommendations about coordination, were agreed with regional sports associations (anglers, boat owners, water skiers and canoeists) and local stakeholders. Institutional coordination prompted management measures involving several governmental agencies at the regional and national level. An example of such coordination was the monitoring of the invasion based on larvae sampling and tracking of the population's distribution and density (Rodríguez-Labajos et al., 2010).

Only after the main management protocols had already been put in place, there was the chance to analyse the experience. This was done together with the officer in charge of implementing the EU Water Framework Directive (WFD) in the Catalan river basin district, within the planning area, who later would become the head of the monitoring and environmental improvement department in the watershed authority (ACA). According to his view, the way how the management measures had been aimed at dragging the BAU towards a more integrated intervention and more ecosystem-based management, that is, towards a 'Shangri-la' scenario. This shift was not encouraged because of the evidence of a bottom-up request, but because these two aspects are among the basic principles of the WFD (Antoni Munné, pers. com, 2007). In particular, there was an aim at developing prevention and mitigation measures based on shared responsibility and active public participation as well as pursuing the good ecological state of water bodies, both guiding principles of the Directive.

That said, it would not be accurate to state that the BAU reached a 'Shangri-la' situation for all elements considered in the storyline in the Ebro River study area. Limited (and declining over time) economic resources, together with strong barriers for institutional coordination despite the good will between the different parts, played against this. Still, the exercise was helpful even beyond the original study area, as helped to understand drivers for establishing preventive measures in other parts of Catalonia. The information about the experience in the Ebro was also the base to analytically develop management scenarios in pre-invaded areas, as reported in next section.

4.3.4 Scenarios pre-invasion: the zebra mussel in the Ter reservoirs[20]

The purpose of this section is to develop scenarios in the pre-invasion phase in an area that is currently influenced by the driving forces of the zebra mussel invasion. The aim was to identity plausible (and mutually exclusive) alternatives that improve the information base of management policies. Based on these alternatives, it is possible to generate proposals that may help to prioritise interventions.

4.3.4.a Methods

The procedure for scenario development in this case encompassed an analytic process that included the following steps:

1. Selecting the area of reference. This entails both the ecosystem where the invasion would be taking place and the socioeconomic area of influence of such ecosystem.
2. Identifying the driving forces that configure the invasion process in that area. This means recognising the mechanisms inducing the introduction, the establishment and the kind of impacts of zebra mussel in the reference area. Having in mind the specific actors and sectors related to such mechanisms is relevant to better understand their motivations and likely actions during the invasion.
3. Identifying the policy strategies or management alternatives with the potential of shaping effectively such driving forces. To this end, literature review and with the dialogue with stakeholders were useful to recognise basic aspects in the policy design (e.g. political ideologies, habits or inertias from the past that have an influence in the management of aquatic ecosystems).
4. Recreating the key relevant stages along the invasion and associated turning points, together with key sectors and processes participating in each stage.
5. Developing coherent narratives that characterise these management options. The storyline needs to consider what is to be expected in each scenario for each stage of the invasion process. In particular, it is important to define the direction taken in face of a turning point, having in mind the most coherent management decision in each policy strategy. This direction should be grained according to the prevalent technologies, institution, economic activities in the assessed context.
6. Illustrating scenarios with indicators, the plausible evolution of which may be estimated through different techniques.

[20] This section was developed with support from the Spanish Ministry of the Environment in Research and Development (R+D) Project No. 072/SGTB/2007/1.1. I am grateful to Samanta Benaiges and Núria Julve, who assisted the last stage of the research and developed related bachelor degree dissertations in environmental sciences at the UAB under my supervision.

Next section shows how this procedure was implemented in the case of invasion scenarios in the non-colonised area. The process was entirely analytic, although informed by participatory methods in two ways. First, it is rooted in knowledge from the previous participatory scenarios from the Ebro River in 2005-2006. Second, it is an outcome of the ethnographic process of working within the main organisation in charge of aquatic invasive species control, particularly during the period 2006-2010.

4.3.4.b Results: management scenarios in the Ter reservoirs

This section includes the description of the plausible events of different courses of the invasion process of the zebra mussel in the Sau-Susqueda-El Pasteral area. Specifically, the process that aims at being represented involves three basic constituents:

- The introduction of the zebra mussel in the area, via transport of adult individuals or larvae from invaded areas and its establishment (along the whole life cycle including the reproduction).
- The kinds of management interventions that are likely to be applied in response to each phase of the invasion.
- The impact of the presence of the zebra mussel in the socio-economic activities of the study area and its area of influence.

In order to figure out how this sequence takes place under each scenario, the procedure outlined in **section 4.3.4.a** would start from the selection of the study area. This area is the system of reservoir in the central course of the Ter River and the reference information is the detailed description that has been presented in **section 1.4.4** (The situation in the internal basins of Catalonia).

Next if follows an identification of driving forces operating in the area. Building or previous results from the dissertation, the information from **section 2.2.3** (Generalisation of the factors in the invasion of the zebra mussel in Catalonia) and, in particular, the factors of the invasion and related management measures presented in **Table 23** are used to complete this part.

The rest of the steps in the scenario development (from step 3 and following) are developed next.

- *Identification of the policy strategies or management alternatives*

A necessary step to define the management scenarios is to specify the objectives of each management alternative. To this end, the distinction made by Perrings (2005) between mitigation and adaptation responses in the field of bioinvasion is taken into account. The common 'do-nothing' idea is represented though an extreme scenario of total lack of intervention. Finally, the measures undertaken by the administration are included in a business-as-usual (BAU) scenario.

Table 51 Management scenarios: objectives and description

Source: Own elaboration

Scenario	Objective	Description
I. Do nothing	No IS management objectives are specified	It entails a complete lack of intervention along the invasion process. No monitoring, prevention or impact mitigation action is undertaken.
II. Mitigation	To reduce the likelihood of the adverse event of each phase of the invasion	There is an emphasis in the prevention of the arrival and establishment of the species in the area. If this happens, prevention of impacts becomes the priority.

III. Adaptation	To reduce the size of the invasion impacts	The irretrievable invasion by the zebra mussel is assumed, so all energies put into prevention will not be fruitful in the long run. Therefore the efforts concentrate on adapting the users to the unavoidable arrival of the species. There is an emphasis in the mitigation of the impacts.
IV. BAU	Business-as-usual	It describes the measures already put in place and those that can be expected if the current policy of action remains unchanged

- *Identification of the policy strategies or management alternatives*

In order to develop the four scenarios, it was clear the need to specify the different phases during the invasion process. The identification of such phases comes from the experience of facing them in different moments of contact with such the

- **Pre-invasion**: Whereas diverse driving forces are operating, there are not evidences that the invasion has already taken place. An area can be consider in the pre-invasion phase when 1) there are physico-chemical factors and conditions of the water body that make it prone to be invaded, and d) there are factors of larvae and/or adults introduction.

  In practice, this is the common situation in any area under the responsibility of an administration. Still, risk assessment (such as that illustrated in **section 4.1**, may help to point out those most under pressure. In Catalonia practically all reservoirs that are not in the following two categories can be considered in a pre-invasion context.

- **Pre-alert**: There are signals of the invasion, although it has not been confirmed. The pre-alert is activated once larvae are occasionally detected at very low densities.

  In Catalonia this situation took place in several reservoirs of the Ebro basin since August 2007, when the CHE reported occasional detection of larvae in the reservoirs of Sant Llorenç de Montgai, Talarn and Rialb (and others afterwards), without evidences so far of massive colonisation by the zebra mussel. That meant an unforeseen management situation. Previously the belief was that the first detection of the species would mean the application of all control measures at once. However the persistent lack of confirmation shows that some preventive measures can and must be applied, but compromising all uses it is not required. The first moments of alert can be employed to unite efforts in the preparation of the following phase, but being too restrictive needlessly undermines social support to future preventive measures.

- **Invasion alert:** There is a confirmed and frequent detection of larvae or detection of adults. The colonisation of the water body should be expected, according to the biological model of the invasion.

  This is the situation of the colonisation of La Baells reservoir, in the Llobregat River, the better example in Catalonia.

- *Development of coherent narratives for each management alternative*

  Having these three phases in mind, next each scenario is developed by inferring the kind of management measures which may be expected in each stage. Again, this is based on the best

available knowledge about what has happened in the past under similar situations, together with information about current management practices.

Table 52 presents the storylines, specified as answers to key questions along the invasion process. A particular detail to have in mind is the relevance of some turning points that mark a milestone between invasion stages (e.g., when does the introduction take place? When does the establishment occur? What does confirm the invasion?). Looking at the storylines, the different scenarios turn out to be different each other, particularly in relation to these turning points.

Table 53 Management scenarios in the pre-invasion context - Source: Own elaboration

Key elements along the invasion process		Do nothing	Mitigation	Adaptation	BAU
*Which actions during the **pre-invasion** phase?*		Neither monitoring nor preventive information campaign with involved sectors is carried out No protocols for involved stakeholders / sectors is prepared	Intensive monitoring (larvae and adults) Information to all involved sectors Design of guidelines for action for all sectors Resourcing (infrastructures and preventive equipment)	Moderate monitoring Information campaigns with sectors related to infrastructure management Adaptation of the irrigation systems Adaptations of water supply systems with upstream intake Improvement in the water treatment system of the Pasteral reservoir (filtering/pre-treatment in the reservoir)	Moderate monitoring (larvae) Protocols for sectors linked to navigation Confinement of motor navigation in Sau, ban to navigation in Susqueda and El Pasteral Authorisation to canoeing in Sau and in the river section between Susqueda and El Pasteral
When does the zebra mussel introduction takes place?		At any time, in any of the reservoirs	Belated or not happening, in Sau	Belated, in any of the reservoirs	Belated
*How is the **pre-alert** activated?*		It is not activated	After the first detection of larvae, or detection of the species in neighbouring reservoirs	After the first detection of larvae	After the first detection of larvae, or detection of the species in neigboring reservoirs
Which kind of rapid response measures take place during the pre-alert phase?	*Monitoring*	None	Intensification of monitoring and surveillance measures to confirm the detection	Intensification of monitoring and surveillance measures to confirm the establishment	Intensification of monitoring and surveillance measures to confirm the detection
	Angling	None	Angling suspended	Possible temporary suspension of angling	Informative campaigns, angling not suspended
	Navigation	None	Navigation suspended (motor boats and canoes, in all the area)	Navigation confinement (motor boats and canoes, in all the area)	Navigation confinement (motor boats and canoes, in Sau). Confinement or navigation ban for canoes in the section between Susqueda and Pasteral reservoirs
	Management of infrastructures	None	Intensified pre-chlorination of water supply in the Ter ETAP Management of water level in all reservoirs	Guidelines for actions activated Start of the pre-treatment in the Pasteral reservoir / Start of the treatment in the irrigation systems Management of the water level in the Pasteral reservoir	Intensified pre-chlorination of water supply in the Ter ETAP
When does the establishment occur?		At any time, in any of the reservoirs	In the Susqueda reservoir and, soon after that, in the Sau reservoir	In the Susqueda reservoir and, soon after that, in the Sau reservoir	In the Susqueda reservoir and, soon after that, in the Sau reservoir
*Which circumstance confirms the invasion **alert**?*		Establishment of adults, evidence of massive impacts	Establishment of adults, frequent detection of larvae	Establishment of adults	Establishment of adults, frequent detection of larvae
Which systems suffer impacts after the establishment?		All systems (water supply, irrigation, power production)	All systems, with lesser intensity in those infrastructures that can be managed	All systems, except for those infrastructures that can have been adapted	All systems, with lesser intensity in those infrastructures that can be managed

- *Illustrating scenarios with indicators: estimation of impacts*

Another way to distinguish the scenarios each other is to understand their differences in relation to the associated impacts. The whole **section 3.4** builds on the scenarios just developed to estimate possible monetary impacts from the scenarios 'Do nothing', 'Mitigation', and 'Adaptation', and for four moments of the invasions: the pre-invasion context; the first alerts of the invasion; the post-invasions moment, when there is evidence of massive impact, and the permanent post-invasion situation. The interpretation of those results, not repeated here for simplicity, also supplements the storylines and the narratives associated with each scenario.

4.3.4.c Utility for management of analytic scenarios

Pre-invasion scenarios constitute a basic element for the development of preventive measures. In this case the different futures have been systematically explored having in mind the strategic decision of which kind of policy should be deployed. In this respect, they are clearly scenarios, and not prognoses, as the narratives differ significantly each other.

A clear example is the type of impacts in each case, which depend on stakeholders' choices. The exercise also helps to distinguish the elements of the response that do not depend of stakeholder's behaviours or management decisions (e.g. the location of the water body, certain physico-chemical characteristics of the water body). These elements encompass infrastructures that are vulnerable to the impact of the species, and whose adaptation is not feasible or technically challenging in the short term. For this, analytic scenarios as the ones presented can be easily complemented with risk assessment (eliciting plausible areas of invasions) or with probabilistic tools that give a more precise idea of what can happen with them.

The scenarios just presented where developed based on a reflective 'knowledge from within' and synthesise years of daily contacts with the management of zebra mussel in Catalonia. A test of consistency was to present results to the water authority in September 2014, once the author was no longer part of the management team. In the meantime, the detection of several water bodies in the IBC colonised by the zebra mussel, still relatively far from the study area, had to be dealt with in the context of reduced resource availably from the water authority.

For this test, after an introductory presentation of the scenario results and clarification of possible questions, four questions were made and discussed. The results of the deliberation are presented next.

- *What is the desirable scenario in terms of the WFD?*

'No action' is clearly not an option, not only because of the magnitude of the potential costs involved, but because the current situation is already different from that scenario.

As the WFD urges the achievement of good ecological status or good potential, in principle, 'Mitigation' seems a scenario that aims at defending the environmental conditions the most. However, there are two important nuances to this reasoning. On the one hand, it is not clear that the effects of the zebra mussel on the indicators used to assess water quality are inevitably negative. In fact, it might happen that some of these effects are positive for the performance of the metrics used, and therefore, preventing the entrance and establishment is not a must, just having the implementation of the WFD in mind. On the other hand, the achievement of the good status (or good potential in this case) is not the only basic principle of the Directive. The consideration of water pricing policies for whole water cycle and the balancing of interest of the environment with those who depend on it may advise against scenarios that defend the environment at any cost, in particular if such cost is not affordable.

In this respect, the distribution of costs over time is very different in 'Mitigation' and 'Adaptation' (see **section 3.4.2**). For a consideration of the most advisable scenario that accounts for economic principles, estimating the future savings activated by investments in the pre-invasion phase would be advisable. In order to prepare a meaningful comparison of scenarios, knowing the probability of each one of the events (e.g., activation of the pre-alert, establishment, etc.) along a timeline is essential. Yet the occurrence of such events is uncertain and it changes between scenarios. Hence their probabilities are not available and a risk-based comparison are is viable.

- *Where is the BAU?*

The current situation tends more to 'Mitigation' than to 'Adaptation'. Given the scarce funding available to develop AS management measures, inaction takes place beyond the deliberate decisions of the managers. In order to explain this, one of the interviewed officials located BAU within a triangle, near the midpoint in the edge between 'Mitigation' and 'Do nothing'.

- *What is the scenario to be expected?*

'No action' is not to be expected, as the current situation already involves activities of both 'Mitigation' and, into a lesser degree, 'Adaptation'. The current economic context makes it difficult to fund adaptation measures. Together with this there is a problem because 'Adaptation' requires considerable investments that perhaps are never required. This rationale is very different from the way how public administration plan and implement management. Since administrations find hard to compromise investments for uncertain futures, while there are topics that require immediate attention and offer results in the short term, the most plausible scenario is then 'Mitigation'.

- *What utility this can have for water management? And for local stakeholders?*

This type of scenarios allows stakeholders to identify the management options best fitting their interests. Thus, 'Mitigation' is problematic for recreational users (anglers, boat holders and canoeist), because it is a scenario that restricts the variety and intensity their activities in the area with the rationale of preventing the entrance of the invaders. Meanwhile, 'Adaptation' allows these stakeholders to develop such activities, while at the same time does not require them the bulk of investments, which are rather incurred by the majors users of the reservoirs (water managers and hydroelectric sector and administrations).

For other stakeholders, like administrations and water managers, deliberation based on scenarios may be helpful to get greater insights about necessary changes in management, such as opting for a different strategy for monitoring. Another useful element is visualising the current situation in relation to possible strategic shifts. Managers become thus more aware not only about the implications in terms of possible costs of action and inaction, but also about the position that can expect from other stakeholders in each one of the possible scenarios.

In this respect, from the above it can be understood that, while the management strategy tends to favour 'Mitigation' as the scenario that is more consistent with the current policies of water management, 'Adaptation' may be more consistent with the interests of the stakeholders related with recreational activities. The policies of water management operate at the regional scale, while the recreational stakeholders have a direct contact with the local processes and are, in fact, associated with the direct drivers of the invasion. In this respect, how stakeholders at different scales are positioned in relation to the scenarios and how this can be approached from a methodological point of view is also a relevant research question. This is the topic addressed in the next section.

4.3.5 Scenarios, scale and agency

4.3.5.a Multi-scale interaction in local-scale scenario development

Despite its popularity, a review of the scenario literature reveals some missing elements regarding multi-scale interaction in local-scale scenario development. Local areas are not independent entities isolated from the larger economic and social forces acting on them. Localities are influenced by a web of global (globalisation), regional (e.g. EU policies, EU enlargement), national (e.g. trade policy, agricultural policy) and local (e.g. power relations) forces that involve a multitude of feedbacks and interactions (Kok et al., 2006b). Yet, in the scenario literature, scenarios built at the local level that take national and global developments into account, have so far been limited. Today, there is growing interest in linking scenarios at various geographical scales, and new contributions include the VISIONS project (Rotmans et al., 2000), subglobal scenarios linked to the Millennium Ecosystem Assessment (MA) (Lebel et al., 2005), the MedAction project (Kok et al., 2006a), the SCENES project (van Vliet and Kok, 2007) and the AG2020 experience focused on the EU agriculture (Stratigea and Giaoutzi, 2012).

A remarkable effort and a key contribution to linking scenarios developed at various geographical scales is that of Zurek and Henrichs (2007), who systematically describe concepts for scenario development processes and discuss how scenarios can be coupled (or not) across geographical scales. However, the authors do not provide a detailed account of when to use each process: "*which process is best suited and how much interconnectedness is needed, will depend both on the focal issue and the primary purpose of the scenario exercise*" (Zurek and Henrichs, 2007: 1282).

In fact, while discussing the multi-tiered structures and the interaction of multiple forces, Biggs et al. (2007) argue that formal approaches for linking local scenarios across different scales are currently not yet very well developed. The work by Zurek and Henrich mentioned above classifies ways of coupling (or not) the scenarios. However, in this classification, scenario exercises usually focus on processes at a specific location and are built independently across scales. As a result, while comparable across scales and useful for engaging people in decision finding processes, they omit relevant dynamics of interaction and outcomes. For instance, as noted by Greeuw et al. (2000), the POSSUM team (1998), in which sustainable transport goals for the year 2020 are formulated, seems to have treated Europe as an isolated continent. Similarly, scenarios developed in *World Water Vision* included both a set of global scenarios and a variety of substantially different regional scenarios developed in independent scenario exercises. Of course, there is no problem with such attempts, if one considers these issues solely regional, in other words, as decoupled from issues at global scale.

Alternatively, there are some more tightly coupled multi-scale scenario exercises; but these are primarily either top-down (namely, equivalent across scales), with an emphasis on downscaling higher level processes, or hierarchical (namely, consistent across scales), setting the more aggregated level as a boundary condition for any lower level of aggregation (Kok et al., 2006b; Özkaynak, 2008). According to Esteva and Prakash (2004: 410), this is mainly because in an increasingly global capitalist economy and given the rise of supranational institutions, the significance of the nation-state is declining and localities navigate in a sea of globally generated constraints and imperatives: "*more and more voices are raising alarms about their growing sense of powerlessness, tugged and pulled by 'global forces*". Similarly, Noronha et al. (2002) argue that global forces are becoming so powerful, the main constraints on sustainable futures at the local level—and sometimes at the national level—seem to emerge from the 'room to manoeuvre' available in making choices.

In this context, adopting a strict downscaling methodology, while maintaining consistency across scales to allow for comparison of scenarios, potentially limit scenario variability and stakeholders' creativity and omit power relationships among stakeholders at different scales (Kok et al., 2006a). For instance, in the MedAction project that focused on land degradation and desertification in Europe and in the Mediterranean region, local scenarios ended up being largely similar to the three Mediterranean-level scenarios. Here, the problem was that information on general attitudes, such as 'Europe is more environmentally friendly', was directly translated into local scenarios in a creative manner 'ecotourism will bloom', 'small-scale agriculture will prevail', 'windmill parks will be built' without questioning the local conditions, i.e. the probability of growing tourist numbers in the specific region. However, as Greeuw et al. (2000) also note, although this is an attempt to address multiple scales, it is just a 'one-way-integration' where local scenarios basically lose their relevance to decision-makers at the lower scale.

Needless to say, while external forces can be particularly strong, they are not the sole influence on localities. Local driving forces, and social actors and coalitions in the local environment also play crucial roles in the future of a region. Although global forces have become increasingly important, Öniş and Şenses (2007) argue that for these forces to be effective in terms of accomplishing the implementation of policy, the parallel development of a supportive domestic coalition is required. This is also consistent with the argument that a structural analysis, that is an analysis at the macro level, cannot be deemed adequate until it specifies the political process through which systematic imperatives are translated into lower level policies (Mollenkopf, 2003). In this context, global powers are built on shaky foundations, and given the right conditions they may be effectively opposed through local action (Esteva and Prakash, 2004). In that regard, there is extensive literature which stresses that it is the intentions and (re)actions of local agents that determine the viability of a policy regime (Borer, 2005; Byrne et al., 2007; Öniş and Şenses, 2007) and this has not been thoroughly explored in local scenario methodology. Local scenarios thus far appear to underplay the importance of local politics and the potential for community action, since these have not been part of the analytical picture in general.

4.3.5.b The local scale and the larger scale: strategies for interaction[21]

The existence of multiple forces operating at various spatial scales poses empirical and theoretical problems, and over the past decades numerous theorists have addressed this problem of interaction (Alfasi and Fenster, 2009; Gibson et al., 2000). Flyvbjerg (2001), for instance, notes the difficulties of attempting to simultaneously account for the structural influences that shape the development of a given phenomenon and still craft a clear, penetrating narrative or microanalysis of that phenomenon. The author also highlights that research linking macro-level factors and actors' choices in a specific social and political context, has so far only been addressed by disconnected projects. Yet, following Bandura (2000: 77), a full understanding of human adaptation and change requires an integrative assembly of external influences and self-influence, since human agency operates generatively and proactively on social systems.

In this context, this section explains in more detail how scenario development constitutes an integrative framework for analysing inter-scale interactions, and proposes a procedure to account simultaneously for global influences and local factors in scenario development. Specifically, this procedure consists of

[21] This section reproduces, with permission, some parts of the paper 'Multi-scale interaction in local scenario building: a methodological framework' (Özkaynak and Rodríguez-Labajos, 2010).

first, overlapping driving forces considered at different scales, and then checking to see whether they are consistent across scales. Here, any consistency across driving forces at different scales would lead to positive feedback loops. In case of inconsistencies, the plausibility of possible local-level reactions would be subject to the varied agency capabilities of actors/coalitions. In other words, given the different agency capabilities of actors/coalitions, it is also plausible for scenarios to be inconsistent across scales.

Hence, based on agency capability at the local level—as defined and analysed in the **section 2.3**—two strategies of local scenario development are explored: accommodation and reaction.

- *A strategy of accommodation*

Taking the city-region case as an example, Ravetz (2000) argues that many elements of local-level scenarios are necessarily linked explicitly or implicitly to a national scenario, which in turn, is governed by a European or a global scenario. When local areas are not complete masters of their own destinies, a number of economic, demographic, social, political, technological and natural factors have varying degrees of influence on urban patterns, as well as on one another. In places where local agency capability has been qualified as low, reaction scenarios are seen as implausible. In such cases, external driving forces are considered paramount in shaping the future of the local area; they boast the greatest potential to motivate fundamental changes and deviation from current trends, and make the difference between the possible trajectories. Consequently, scenarios are generated and developed from the start with the boundary conditions of the larger scale.

Certainly, when accommodation is the assumed strategy, the seeming compliance of the local context does not necessarily imply a lack of reaction. At times, the accommodation strategy is also a sign of local efficacy. Some local-scale coalitions may deem that their interest is a conduit of the external influences at the local level, and hence decide to adopt the external configuration of a problem as a rational strategy. With high agency capability, such coalitions may also play key roles in the parallel development of supportive domestic circumstances. In this context, Öniş and Şenses (2007) argue that global drivers and local forces/coalitions moving in the direction of these global drivers usually strengthen the impact of one another, and facilitate the process through which systematic imperatives are translated into local policies.

Needless to say, the costs and benefits of the accommodation strategy are not equally distributed. The pre-eminence of the larger-scale scenario usually benefits the particular interests and values of the supportive coalition dominating the local level. And since opportunities for influencing the local setting are not evenly distributed either, those that could be in favour of resistance become merely a weak opposition and take part in the institutionalisation of the context they aimed to resist, if their agency capabilities are low.

- *A strategy of reaction*

While larger-scale scenarios may set the boundary conditions for local scenarios, given the right circumstances, the scope of events can also include bottom-up influences. The plausibility of such interactions relies on the capability of the local context to counterbalance pressures from the larger scale, and thus requires a high degree of agency performance. Here, internal and external driving forces interact without the particular dominance of the larger scale, and inconsistency across scales becomes a valuable asset in understanding the plausible dynamics of the scenarios.

If external and internal driving forces for future developments are in accord, the local scale will consent to operate within the structural influences. The intensity of external development will even be accentuated

by positive feedback from the assenting local context. Yet, any potential discord across structural influences and dominant local drivers and/or coalitions with high agency capability is likely to produce discrepancy and resistance from the local context. Here, resistance entails persistently facing those external pressures that are perceived as threats to local development, and involves a deliberate or spontaneous desire to control the possible adverse outcomes of the external influences. Unless the larger scale has a specific vested interest in the changes produced at the local scale, such as the direct consumptive use of local resources, resistance by local coalitions are likely to succeed. Due to the enhanced properties of high agency capabilities, the strength of local coalitions with a higher sense of attachment and belonging is likely to enable local interests and values to prevail. This explains successful resistance even in contexts of violent suppression of opposing movements (see, for instance, Malseed (2008).

4.3.5.c Inter-scale interaction for the Ebro scenarios

In **Chapter 2**, bionvasions processes in general and in the Ebro in particular have been analysed as the outcome of multi-level driving forces, operating many of them outside the limits of the local level. For this reason, it is interesting to understand plausible futures beyond the local or regional level, as the ones contained in the scenarios developed in this chapter so far.

Given the emphasis brought on policies and lifestyles as types of driving forces, a reasonable unit of analysis to represent the larger scale in the case of the Ebro is the European Union. Then, based on literature review it is possible to generate precise assumptions regarding the evolution of socio-economic driving forces of biological invasions, in the case of three alternative policy scenarios for Europe proposed by the research team in the ALARM project (Spangenberg et al., 2012).

In particular, three narratives about risks to biodiversity at the EU scale, based on ALARM scenarios were available: (1) BAMBU (business as might be usual), extrapolating the expected trends in EU decision-making and assessing their sustainability and biodiversity impacts; (2) GRAS (growth applied strategy), liberal, free-trade, globalisation and deregulation scenario; and (3) SEDG (sustainable European development goal), integrated environmental, social, institutional and economic sustainability scenario Based on them, the narratives for the specific issue of biological invasions at the EU level were expanded consistently. The full methodology and process is reported by Rodríguez-Labajos (2006). Here only the final storylines are presented, in **Box 6**.

Box 6 Three scenarios for bioinvasion in Europe

GRAS, a tale of lost identity

GRAS scenario allows the intensification of nearly every driver of biological invasions, many of them with very rapid increase.

Economic processes reinforce the introduction of invasive species. The increase in physical trade, as well as the intensity of transport and tourism, extend the number of arrivals from long distances and keep accumulating critical masses of invaders. Survival of these species is enhanced by the speed of transport. The probability of accidental releases increases with the recurrent frequency of commercial and tourist routes.

Monetary trade flows from Latin America and Africa stagnate, but increase in physical terms, especially for raw materials, including those commodities more prone to give be hitchhiked by invaders (such as seeds, micro-organisms and insects). Arrivals from East Asian countries increase; transport routes from China and India emerged as new invasion corridors. Economic growth of these countries improves their internal transport networks. The Euro-Asian road transport increases. Together with the present trend in climate change, two factors promote the establishment of introduced species.

• Agriculture, cattle management, forestry and aquaculture opt for monoculture production of market-valued commodities. Some of the productions are based in the exploitation of alien species, whose adaptation to the European biophysical conditions is enhanced. Use of GMO becomes a common practice to this end. Alien species and GMO are accidentally released. Pesticide use must increase because monocultures have turned the cultivated lands into less resilient areas to invaders.

• Expanding human infrastructures and urbanization extend the areas prone to invasion, by fragmenting landscape and by creating invasion corridors within the European ecosystems. The spread rate of invaders increases.

As a result, the number of invasive species increases for all taxa. This will cause biodiversity loss. In spite of the high damage costs and high control costs, action against bioinvasions is limited. Such costs are neglected, compared to the general benefits of laisser-faire economic growth.

Responses toward invasive species damaging economic assets (infrastructures, commercial crops and harvests) are required. They adopt those 'easy' solutions that, inside the soft regulatory framework, match with the mainstream economic interest (pesticides, GMO). Impacts on human health of both biological invasion and their control are tolerated except for the few incidents where liabilities are clearly demonstrated.

Taking into account the deteriorating public health systems and the polarization of income, poorest and least powerful strata are the victims of the process. Urban poor communities and inhabitants of depopulating rural areas become clients of new products for invasive control or develop their own adaptation strategies. Occasional episodes of social reaction blaming those actors that drive bioinvasions and produce pollutants have not had repercussion in the media or in the policy action.

Lifestyle is defined by material consumption. Former sense of place has been replaced by homogenized stages, set for common consumption patterns. Accordingly, lack of social interest in biodiversity is part of a broader lack of interest in nature conservation as an expression of identity. Availability of exotic biota as commodity does not generate social concern since aliens only matter as long as they cause economic costs. Accidental releases of species for pet and aquarium (small vertebrates, some invertebrates) and ornamental flora increase because of such neglect.

Defined by business opportunities, research agenda focuses on innovative technical solutions for fighting against pests, namely biotechnology.

BAMBU, a tale of political correctness

BAMBU scenario represents a Europe where most of the trends for introduction and establishment of invasive species remain, and some of them increase in intensity.

Due to the implemented policies, some driving forces of biological invasions are controlled to certain extent. Eco-taxes on air travel have entailed the stabilization of tourism flows. But tourists still prefer long-distance trips and participate in both intentional and unintentional introductions. Frequency of unintentional introductions intensifies due to the rise of physical trade volumes. The profile of international trade activities is the same described in the GRAS scenario: a) Sustained physical flows of raw materials from Latin America and Africa contribute to hitchhiking seeds, micro-organisms or insects; and b) Increased material flows from East Asian countries reinforce air and marine invasion corridors from China and India. Euro-Asian road transport increases as a result of the improvement of internal transport networks within these countries, especially in China. Within the EU, the extension of transport networks and their intensive use facilitate the spread of invasive species. Road pricing is the only obstacle, by limiting road transport volumes.

Thus, the inflow of invasive species is constant. However, the species find some barriers for establishing. Although the trend to urbanization favours bioinvasions, an aim of nature conservation pushes some policies, like CAP, towards landscape maintenance. The network of protected areas is extended.

However, these actions are kept in the frame of dominance of economic interests. This means that control actions are taken after pondering the costs to economic activities over the abatement costs. There is not a coordinated action between different actors, but specific initiatives held by affected actors. Technical solutions tend to promote the use of pesticides, and less, of GMOs. Health concerns give rise to tensions between users of pesticide and the public, which seeks protection in the upgraded Biocide directive. This situation is used by the industry as an argument to defend research in GMO as 'healthier' alternative. Still, public resistance to GMOs prevails.

For the rest, preventive policies are pursued by supporting weakest-link countries. Interest in external markets is only a part of the external relationships of EU. Two factors rise as source of emergence of new donor regions that require

preventive efforts. First, the enlargement of EU extends to Turkey, Ukraine and Balkan countries. Second, development cooperation is strengthened, which implies bigger exchanges with third countries of minor institutional capabilities for controlling bioinvasions. Facing this, two kinds of measures are adopted: an additional pressure to domestic inspection systems and some support to the controls systems in developing countries.

Research agenda on biological invasions focuses on technical solutions for controlling biological invasions. Educational programmes supporting nature appreciation are also required by a part of the society.

SEDG, a fairy tale

In contrast to previous storylines, SEDG scenario allows visualizing a Europe where some of the driving forces of biological invasions subside.

Several factors reduce the intensity of the invasive species introduction. Thus, the drop in physical trade volumes turns out to reduce the need of transport practices. Far East countries (over all, China) still raise as new main actors of international trade. For this reason, transport routes to these countries keep opening the new invasion corridors.

The fall in the long-distance tourism lessens introductions of invasive species to the EU. But the rising short-distance tourism is a factor for promoting biotic exchanges between European biomes. For this reason, an increased attention is given to the nature of eco-tourist activities. Some recreational practices with implication in fauna management (e.g. angling) are revised for avoiding their contribution to biological invasions. Preference for native species prevails in land management together with a renewed interest in traditional practices as sign of own identity. This way, both organic farming and adaptative management play in favour of native ecosystems. Although reaction against aliens is not a deliberate strategy, farmers act with increased consciousness about the implications of the presence of invasive species. In this way, they develop an effective guardianship on local resources.

However, some factors play against the control of biological invasions. Urbanization is still a trend that promotes the establishment of invaders. On the other hand, the boost to rural life means that all intensity human settlement spreads all over the European territory. Neo-rurals become a source of secondary releases of alien species, but at the same time they exert stewardship of rural areas. Abandonment of previously cultivated lands (and subsequent decrease in Human Appropriation of Net Primary Production) is a double-edge process. On the one hand, it offers space for more biodiversity. But, by offering areas for the succession of vegetal communities, it also opens spaces for those invasive plants that are better competitors. That enhances the establishment of invaders in many unused lands.

Multi-lateral cooperation (e.g. aid trade) and acceptance of refugees entail an increase of biotic exchange with areas under less severe inspection and control systems. Thus, an increase of unintentional introductions takes place. The response entails an increase of supporting programs towards these developing countries.

Sense of place and resources in environmental education have made of sustainability a basic ideological guideline for acting towards invasions. Two kinds of responses are taken. On the one hand, each specific invasion is systematically assessed with stakeholders' support. Vigorous control and effective mitigation measures are taken only in some cases. On the other hand, the very concept of biological invasions is deconstructed. The capability of adaptative management takes the place of a general bioinvasions policy.

Then a question would be how to the local scenarios in the Ebro developed in **Section 4.3.2.b** and the larger-scale scenarios just introduced interact. A simple methodology, introduced by Rodríguez-Labajos (2006), and further refined by Özkaynak and Rodríguez-Labajos (2010) was used to this end. It involves a) the assessment of local agency capability to understand which strategy from the ones described above (accommodation or reaction) can be expected in the region; b) overlapping of the scenarios at the two scales; c) characterisation of consistency between the scenarios at the two levels and d) characterisation of tensions and description of ensuing plausible trends.

In the Ebro, local agency capability was identified as being high (see **Section 2.3.2**). Therefore, employing larger-scale scenarios just as boundary conditions (accommodation strategy) was deemed an inappropriate methodological decision. Likely bottom-up influences were acknowledged aand a reaction strategy was therefore used as the basic approach to build the local scenarios.

Table 54 Inter-scale integration (EU and the Ebro River), Source: Own elaboration

Table 54 a GRAS

Local scenario	Campi qui pugui	Negoci políticament correcte	Caos administratiu amb bones intencions	Shangri-la
Consistency?	Yes	Consistency between the large scale trends and the preferences of domestic economic actors	Consistency between the large scale trends and the institutional conditions.	None
Tensions?	No	Demands from the national / regional administrations towards the UE institutions Political tension but social indifference	Citizens' demands are neglected by the administrations.	Tension regions – UE Why some regions are able to defend themselves in front of the large scale dynamics?
Plausible trends?	Described trends emphasize in both levels. Vicious circle.	Possible downloading towards a GRAS profile	Dynamics towards degradation of social profile. Social concern - Protests	Resistance Alliance of regions (e.g. GMO-free regions)

Table 54 b BAMBU

Local scenario	Campi qui pugui	Negoci políticament correcte	Caos administratiu amb bones intencions	Shangri-la
Consistency?	Considerably with regard to the economic interests	Yes. 'Local BAMBU' with more efficient domestic administrations Domestic economic actors join the chrematistic dynamics of large scale scenario	Yes. 'Local BAMBU' with less efficient administrations Consistency of local actors with the more positive aspects of the European new policies	Only some aspects are consistent
Tensions?	Tension from the UE institutions to national institutions.	They will appear in case that the political objectives of the large scale would not coincide with the local interests guiding political will.	Some of the EU policies are not implemented for the lack of operative capabilities.	Tension regions – UE Why some regions are able to defend themselves in front of the large scale dynamics?
Plausible trends?	Possible advance towards a 'Negoci politicament correcte' if the administrative conditions are influenced by the general trends.	The way to 'Campi qui pugui' is only limited by the ability of the states for keeping administrative coordination Possible demands from the domestic government for the increase of local competences / subsidiarity	Supported by the EU policies, citizens may criticize the performance of administrations.	Social concern – protest

Table 54 c SEDG

Local scenario	Campi qui pugui	Negoci políticament correcte	Caos administratiu amb bones intencions	Shangri-la
Consistency?	None	Large-scale dynamics has not influenced the region, although it has affected the administrations.	Large-scale dynamics has not influenced the citizens but not the administrations.	Yes
Tensions?	Why some regions develop their own profiles? Cohesion gaps? Tension UE / regions	Local interests guiding political will may be more based on economic welfare than in sustainability. Tensions UE/ citizens	Domestic administrations have not been able to adapt themselves to the large-scale dynamics. Citizens taking the lead. Why has this happened?	No
Plausible trends?	Resistance Alliance of regions	Weigh of administrative decisions will define if the evolution will tend either towards SEDG or BAMBU.	Weigh of citizens will define if the evolution will tend either towards SEDG or BAMBU.	Virtuous circle

Next, a hypothetical overlapping of scenario levels was tested to check whether the local scenarios were consistent with the narratives of the larger-scale scenarios (See **Table 54)**. There were a several clearly positive (e.g., *GRAS* and *Campi qui pugui*; *SEDG* and *Shangri-la*) or negative (e.g., *SEDG* and *Campi qui pugui*) answers to this question. Apart from that, situations where larger-scale trends or policies were embraced only by some actors or sectors at the local level, e.g. economic actors or regional administrations, also appeared. For instance, the economic actors in the local scenario '*Negoci políticament correcte*' would favour the *GRAS*, although other actors not so directly linked with economic interests may put into question that scenario.

In fact, sources of possible inconsistency in negative or partially positive answers were identified. Did the inconsistency disclose any specific kind of tension between scales? Here, the analysis revealed aspects such as tensions between administrative levels, divergent economic interests, cohesion gaps, citizens' leadership, or lacking operative capabilities. Finally, trends that could be expected from these tensions were assessed.

The conceivable dynamics highlighted likely top-down and bottom-up effects. The scope of possibilities covered extremes from the positive feedback and reinforcement of the described trends at both levels, to strong resistance taking the form of regional alliances against large-scale tendency. Other options between these extremes included social concern, protest, and partial support to policies, demands for increased local competence or effective subsidiarity, and outcomes determined by the power game between the main local or regional actors, among others.

4.3.6 Scenarios and local management

When issues are complex, diversity of perspectives cannot be reduced. In this context, scenarios become best-suited integrative tools for socio-environmental deliberation, as they rise as effective bridges of communicating diverse standpoints into a single narrative. Thus, this approach produces representations that stakeholders (including managers) may fill with meaning from their respective experience about past events and from their expectations about the future. In this respect, scenario development encourages meaningful debates guided by a common purpose. Based on the experience of this dissertation, scenarios are useful for concrete management needs:

- to generate options that can be compared in terms of the impacts caused by the species;
- to be included as input into deliberation about the effects of the invasions and the organisation of responses
- to prepare concrete management measures in face of different assumptions about the development of the invasion.

The typology and method selected for scenario development depends on the objective of the scenario and the role that it will play in management, having in mind the different advantages and disadvantages of the approach chosen (**Table 55)**.

Recognizing the multiplicity of IS-related drivers and effects contributes to opening black boxes of social behaviour without falling into reductionism. Also, it is possible point out to transitions by overlapping the results obtained for different scales. Not always the seemingly 'desirable' scenario is the one favoured by the actors directly in contact with the local processes. For instance, stakeholders in the Ebro River seemed to prefer less conflicting scenarios independently of the outcome in terms of the specified problem (the invasion process). That shows again that solving conflicts does not necessarily lead to solving problems.

Table 55. Advantages and disadvantages of scenario development

Source: own elaboration

	Advantages	Limitations
Scenario development in general	Scenarios support a precautionary view to the uncertain futures, even when the assessment has been done ex post. They help to face complexity directly, becoming the only possibility when uncertainty is irreducible. They are flexible tools: They integrate many languages and forms of knowledge. Scenario development enhances learning: new information is added to the old knowledge in a meaningful way. Assumptions are stated transparently.	They do not provide crisp results. Assumptions are restricted by the frames of reference of the participants, either stakeholders or the analysts themselves. Information constraints and underlying discourses will be reflected in the outcomes. Assumptions are difficult to test. When they are strictly qualitative, scenarios may be lacking in meaning to those audiences used to crisp results.
Analytic scenarios	Less time consuming, only dependent on analyst agenda. The inclusion of technicalities is only bounded by the ability of the analyst. They can easily target the topic of interest.	Information is restricted to available publications and databases. Risk of excluding relevant views.
Participatory scenarios	Consistency is warranted by stakeholders' participation. Trust building enhances their role as tools for transition. When scenario development meets stakeholders' needs, they contribute with their time and effort. Research cost can be reduced in time and money.	Time and resource consuming. Preparatory tasks, including strengthening of trust and creation of the working atmosphere, are crucial. The focus of discussion can easily move towards themes outside the original topic of interest.

Scenario development also constitutes an integrative framework for analysing inter-scale interactions. An overlapping of scenarios at different levels can reveal affinities or tensions between scales. This can be done through a step-by-step process that answering the following questions: Are the narratives at both levels consistent? If they are not, does the inconsistency reveal any specific kind of tension between scales? Which kind of top-down and bottom-up effects can be expected from those tensions?

In this respect, the results presented above contribute to the growing body of work that views multi-scale scenario-building as a valuable approach in addressing issues of local development and planning. Local policy cuts across a multitude of interests and strategies. It must be formed and reformed, based on the logic of macro level factors as to what is feasible and what is not. Local actors' responses and political judgements about what values and interests they really wish to promote, also play a role. In this context, scenario analysis at the local level provides everyone with an opportunity to examine both the pros and many cons—what is wrong, has gone wrong and can go wrong—of different development paths.

When the storylines are developed, a proper framing within the management context is necessary if the outcome is going to be employed to support policy making processes. The different management domains related with the invasion should be represented (e.g. hydrologic management, angling, natural environment, etc.). A possibility that has not been explored in this dissertation is the consideration of shock scenarios (wild cards) generated through the identification of sudden unexpected developments, the likelihood of which is difficult to estimate.

In retrospect, one scenario that was never considered at Catalan or Spanish level was the invasion by the zebra mussel. Very few people, if anybody at all, had foreseen anything like this.

5 A reflexive management theory for aquatic bioinvasions and a Decalogue for unconventional action

The specialised literature offers a respectable number of guidelines for management of alien species. Among them there are well-established references for the systematic deployment of prevention, eradication and control measures (e.g. Genovesi and Shine, 2004; Shine et al., 2010; Wittenberg and Cock, 2001) or comprehensive handbooks with thorough scrutiny of technical aspects of management (e.g. Clout and Williams, 2009). Any of these works are good reference materials and could – and should – be used to prepare programmes of measures against aquatic bioinvasions.

This section is not going to reproduce what others have been done well in the past. Instead, it focuses on the increasing concern about substantial gaps at the junction of science and policy that are hampering AIS management (Campbell, 2013; Williams and Grosholz, 2008). These are related to the fact that responses to invasions entail manipulating not just the invader itself but also the biotic and abiotic components of the system (Buckley, 2008). Connected to this, there is a concern about the fact that the analysis of AIS management usually focuses on actions needed at the international and national levels, while the critically relevant processes at the local and regional levels are less addressed (see **Table 56**).

Table 56 List of the top 20 AIS issues identified by the delegates of the conference "Freshwater Invasive Networking for Strategy (FINS)"

Note: Scale codes: L- Local; N –National, I – International

Source: (Caffrey et al., 2014)

Issue	Scale
Biosecurity awareness	L/N/I
Coherent EU legislation for effective biosecurity	I
International biosecurity best practice	I
Regulatory framework to prevent introduction of IAS	I
Dedicated and appropriate resources for IAS	N/I
New technologies for early detection	N/I
Early warning mechanisms	I
Rapid risk assessment methods to prioritise future invasion events	N/I
Standardise pan-European risk assessment to underpin EU IAS black list	I
Knowledge gaps in risk assessment	I
The importance of economic analysis in risk assessment	N
Rapid response - a vital tool in IAS management	N/I
Emergency powers to manage IAS	N
Novel control in IAS management	N/I
Knowledge transfer to improve IAS management	N/I
Outreach to foster improved IAS management	N
Effective communication to raise awareness of IAS	N
Non-market valuation in IAS economic assessment	N
Cost analysis in IAS management	N
Single responsible agency -the answer to national IAS management	N

Responding to these concerns, and building on insights from the above chapters, the next concluding pages offer ten policy recommendations for the management of the responses towards aquatic bioinvasions (**Fig 56**). Since each of the chapters has already offered some policy-oriented recommendations, this chapter goes a step beyond this and conceptualises actions that are more generally needed to underpin AIS management in an integrated manner. Linking to the empirical context of the thesis, AIS management is presumed to be an activity led by the public sector, although clearly in

relation to actions and initiatives of many different types of stakeholders with direct links with activities in the field.

The recommendations keep a deliberate level of abstraction, and can be regarded as an action-oriented conclusion from the previous contents of the dissertation. While references, data and examples have been reduced to the minimum, the contents of the chapter are not speculative. Each one of the statements in the sections below can be supported by specific data in the previous chapters, by concrete evidence achieved during the ethnographic phase of the research or are the result of reasoning. As the recommendations set forth some general rules on how to implement effective measures in relation to AS, the chapter is offered as a contribution to the management theory for aquatic AS. In this respect, it is a consistent final step of a reflexive model of science in which "*theory is not something stored up in the academy but itself becomes an intervention into the world it seeks to comprehend*" (Burawoy, 2009: 55).

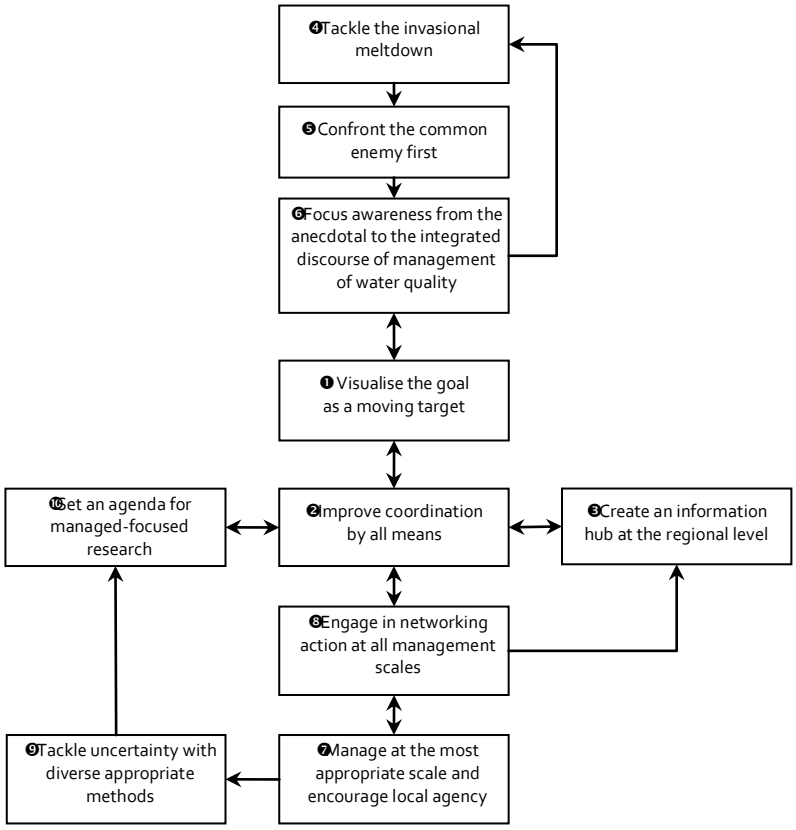


Fig. 50

Policy recommendations in this chapter and some of the synergies among them

Source: Own elaboration

1 Visualise the goal as a moving target

Management of any kind needs an agenda, and in the case of aquatic bioinvasions its purpose must not remain unstated or presumed. The visualisation of an objective should be part of an open exercise that clarifies what it can be considered a successful management. This clarification will unavoidably entail a clash of views about some alien species, seen as concern by some actors, and ignored, or even positively beheld by others. Managers may leap directly to actions based on the consideration of alien species as hazards, moved maybe by precautionary reasons, or by the desire of avoiding inter-stakeholders (or inter-scales) conflicts in conspicuous cases of lack of social consensus. As a result of this, there is a seeming clarity about management objectives, but a reality of disproportionately high dissemination cost (to persuade social actors about the rightness of action) and/or surveillance efforts that are doomed

to failure in a context where the actors driving AIS introduction and spread have more frequent and intense contact with the territory than the managers themselves.

Although it would be desirable, it is highly unlikely that the agendas of the different stakeholders coincide in a way that a collective (pre-emptive) deliberation on objectives takes place in *status quo* situation. In this respect, crises offer unique opportunities to focus the attention of different groups on the relevance of the matter, albeit they give less room of *manoeuvre* to deliberation.

The classical AS management scheme – starting for prevention followed by eradication or, that not being possible, control and impact mitigation – is often used to structure management plans, complemented by risk assessment and monitoring measures. A practical design of responses will bring each of these stages to fine-grained specification of management goals that concentrate efforts there where they are more effective. *Where should be preventing the entrance through early detection mechanisms? Which are the priorities for the species control? Which on-going bioinvasions required detailed impact mitigation procedures and which areas are more vulnerable to such impacts?* Answering all these questions is part of the definition of the objectives for AIS management.

If here we talk about moving targets is not only because of the often relentless spread of some AS. It is also due to the fact that the invasion process comes together with changing priorities for action. So far the most common situation is that the objective of management is very static, once assessed the invasion stage, and the change to a new objective is interpreted as a fiasco in pursuing the previous one. However, invasion processes are by nature very dynamic. Where in the past it was imperative to prevent, today it might be crucial to control populations and in the future it will be necessary to mitigate impacts.

It might happen that managers, aware of the difficulties of an effective control and the discouraging effects of failure, set modest goals that are eventually achievable. Instead of losing battles beforehand, the proposal of a multi-stepped set of objectives helps to clarify a realistic sequence of action: '*The objective is to prevent the entrance of the species A to the area B. Should this introduction takes place, the objective becomes to extirpate the species A from the area B. If this is not possible, the objective is to control (e.g. to restrain or confine) the populations. Together with this, and particularly in case this fails, the objective is to mitigate the socioeconomic and ecological impacts of the established populations of the species A in the area B'*. This does not mean to passively accept the invasion as an inescapable fate – which in fact demotivates the response – but to organise the set of objectives, and hence planning responses, according to plausible course of events according to available information of the species and the context. Even in the case of the most virulent bioinvasions there are likely to be net benefits from delaying impacts.

2 Improve coordination by all means

'Coordination, coordination, coordination' should be the mantra of for AIS managers in aquatic ecosystems. The spread of IAS is not confined by administrative boundaries and the replication of management efforts is clearly a waste of increasingly scarce public resources. This is not news for public managers. The need for enhanced coordination is the most recurrent claim from stakeholders in all kind of participatory processes related with alien species. The scientific community is aware of the utmost importance of coordination, and a plea for public orchestration of measures against AIS appears often in the conclusion of workshops and specialised conferences.

Effective coordination has traditionally faced some barriers. There are indeed practical issues on how this coordination is set up and whether the established mechanism fits the resource availability (including

funding and time availability *inter alia*) of the involved parties. Besides this, for managers engaging in coordination initiatives may be challenging because it usually entails transgressing spaces of responsibility, competence and expertise, while public administration relies on a very strict definition of concrete responsibilities. Organisations that share an interest for controlling AIS may adopt a competitive, rather than cooperative approach, eager to underpin organisational development and budget allocation. Officers may feel uncomfortable in areas where the delineation of this responsibility is not clear, not only in relation with other public actors, but also (and perhaps particularly) in the interactions with non-public actors, the relation to which has traditionally seen as a hierarchical 'command-and-control' rather than horizontal cooperation. There might be also a reluctance to trust in other organisations' skills or capabilities, when the safeguards of quality control are limited.

A major barrier for coordination is also the deception that manager officers may have suffered in the past when previous coordinated agreements made at the technical level were not be able to reach the policy action, due to divergent interest influenced by *Realpolitik*. The realisation that technical sense does not match institutional priorities, political moments, or tensions between organisations may discourage engagement in coordination beyond a shallow 'go-and-see-what-is-going-on'.

In face of all these challenges, and based on insights from the research process, desirable attributes for effective coordination are:

- *Cooperation in practice*. Action-oriented problem solving provides good incentives for the managers to cooperate, because it makes it visible and concretise the significance of collaborating with other organisations and benefits each organisation's performance. Action also helps to accumulate understanding and information about factors of success and failure that are useful for further collaboration.
- *Communication.* This element involves both information exchange between organisations and also the need to communicate the coordination process itself to the public at large. It is a common situation that the public perceives a discoordination despite the fact that the involved organisations are actually working together.
- *Not dominant leaderships*. Not dominated processes avoid antagonisms while at the same time facilitate that the general agenda responds to all the participant's interests. Creative alternatives flourish as the participants perceive that there is room for negotiation in the way how this partnership is developed. Dominating leaderships may be helpful to create an initial focus, but introduce the risk that the coordination process itself is subdued to the interest of the leading organisation and therefore the process becomes unstable.
- *Stable contact points*. Collaboration is a dynamic process. Still it is necessary to prevent excessive learning costs and promote trust by defining stable representatives within the participant organisations who are endowed with decision-making power in relation to AIS management.
- *Enabled local agency.* The foundations for interaction may need to be built from a very basic level. In this respect, underpinning local agency requires mobilising resources at level that is closer to local management, and cooperation should not be restricted to the sphere of decision-making. It should also, and very specially, promote collaboration between agents in relation with direct territorial interventions. Thus, common enforcement campaigns, training, or monitoring need to be developed in cooperation between governmental and non-governmental actors working at the local level. In some cases, this may result in opening up local tensions but also – or

perhaps, as a result of an unprecedented catharsis – stimulating understanding and mutual trust. This point is particularly relevant for coordination of intersectoral activities beyond water management but with influences in aquatic bioinvasions (e.g. involving actors related to agriculture, gardening, trade, coastal management, etc.).

- *Multi-level action.* Local action is needed to strengthen response capabilities. However, the research has shown the multi-level nature of some drivers, which leads to the need to an integrated action ad different scales. This necessary involves actors such as national governmental authorities, social lobbies and the educational system. When the presence of AS is not commonly perceived as negative, as in the case of species used in business practices, this collaboration is particularly important.
- *Regularity*. Emergency situations offer excellent opportunities to mobilise resources for management and the needed political will to cooperate. However if the contacts between organisations only respond to urgency or take place sparsely over time, there might be little chance to strengthen durable common action. Such contacts do not necessarily entail face-to-face meetings and can be vehicled through videoconferences, e-mail listing, or through the regular update of joint platforms as the one mentioned below. The point is to provide keepalive signals and to track progress towards a common agenda.
- *Conflict management*. Satisfactory ways to manage conflicts should be foreseen at early stages of the collaboration initiative. Persistence of antagonisms – between different branches of the administration, between angling societies, between scientific advisors, etc. – erodes the potential for collaboration, even in the most hierarchical systems. The point here is not necessary dispute settlement, but finding a common entry point to facilitate specific alliances around common management actions.

Based on the work done at the regional level and building on the experience of initiatives related to the promotion of partnerships for the control of unwanted organisms, namely the International Plant Protection Convention (www.ippc.int) and the Global Ballast Water Management Programme (http://globallast.imo.org), potential areas for cooperation in the management of AIS could encompass:

- Planning and prioritisation of control measures, such as designing general strategies, drafting regulations, designing inter-institutional programmes and campaigns, including the designation of common priority prevention or control areas, or developing joint specific and inter-specific protocols of emergency response.
- Preparation of harmonised standards and joint implementation of measures tending to improve knowledge about the existing and potential bioinvasions, such as risk assessment and risk management or monitoring programmes.
- Information and knowledge sharing, particularly in relation to: a) collaborative information exchange (on species features, distribution or risk, reference materials, in-coming events, meetings, etc.); and b) experience and knowledge sharing (e.g. monitoring and sampling, successful and failed experience about treatments in infrastructures and measures of direct AIS control); and c) creation of consultative *fora* in support of AIS management.
- Improvements of capacity-building through: a) training and education of governmental officials (technical staff and enforcement personnel), managers of hydraulic infrastructures, irrigation

societies, recreational operators, adjusted to the needs and expectations of the different groups; and b) awareness-raising among the public at large and specific stakeholder's groups.

- Deployment of joint management measures in relation to a) allocation and pooling of equipment; b) signalling, communication campaigns and co-production of informative materials; and c) enforcement and inspection campaigns.

Cooperation certainly involves joint activities in the scope of scientific research. However, in the context of the dissertation, this point deserves particular attention and is elaborated below in a specific recommendation about this matter.

There is a gradient of coordination from unilateral action (no collaboration) to full partnership. Each time there is a chance of interaction, acknowledging the different options is advisable, together with an open recognition of the limiting institutional constraints for each one. A recommendation to bridge the coordination gaps identified in the current state of affairs is to promote as much intense cooperation as possible whenever the opportunity arises.

3 Create an information hub at the regional level

Cooperative action should be fostered by a stable data repository and knowledge-sharing system. This must be properly linked to the aspects of AIS management, from risk analysis to monitoring of populations, at the level that is more useful for organising local and regional responses.

In fact, the compilation of consolidated open databases from what previously was a myriad of information sources about AIS has been one of the remarkable developments during the last decade. The Global Species Database (www.issg.org/database), supported by the World Conservation Union and endorsed by the CBD, has been continuously enhanced in terms of number of species and spatial representation worldwide. The database from the DAISIE project (www.europe-aliens.org), delivered by scientific experts within the UE Sixth Framework Programme, provides updated information not only about species and their distribution in European countries, but also about experts within and outside the scientific world. Recently, the European Commission launched the European Alien Species Information Network (EASIN, http://easin.jrc.ec.europa.eu), which in its final version will be able to deliver species distribution in different formats (10x10 km grid, countries or river basin districts). The EASIN aims at extending the network of partners, now including mostly database managers at the global scale.

In terms of AIS management, the information provided by international initiatives is extremely valuable, as it helps to identify locally absent species that are present in neighbouring countries. However, besides that direct responses against aquatic AIS require timely and precise information at two different scales: regional (all water bodies within a basin district) and local (river sections or other time of water bodies).

In this matter, Catalonia finds itself in a privileged position due to the existence of the ExoAqua (for AS in aquatic environments) and ExoCat (for AIS in general) information systems. However, both initiatives require further development in order to become real information hubs in support of AIS control. In particular, desirable properties of a possible 'hub of alien species in aquatic environments of Catalonia' are:

- *Cooperative effort.* The development of this type of schemes requires time and a large amount of resources, not only for the system design, but also for information input, update and quality control. It could be only useful as long as it is the outcome of a horizontal cooperation and the cost is shared among many users who also benefit from the outcome. This involves water managers and

environmental authorities, but also representatives of other sectors (agriculture, aquaculture and aquarium, sports authorities and federations, etc.).

- *Link to management.* The hub should not only be an information repository but also a decision support system, providing local managers with reliable resources that they can employ in face organising responses, even in the very short-term. Information at the regional level is particularly useful for planning while some activities related with direct management – such as monitoring local AIS distribution and impacts, signalling, control of access, localisation of facilities – require detailed information at the local level.
- *Accessibility.* The system should be open to the public at large. This does not only enhances public communication but also facilitates the prompt identification of information gaps. In this respect, transparency is herein considered a desirable property and what 'good information' is can also be assessed upon users' feedback and their communication of requests and needs.
- *Interactivity.* The information hub we refer here is mostly conceived as a virtual online platform coproduced by several organisations that collaborate in the data search, gathering, moderation and distribution. Data reports should be downloadable and printable versions of the files should be provided for those stakeholders with difficulties for online access to the materials.
- *Interoperative electronic format*. The datasets should be connected to other databases and information systems, either larger-scales databases about alien species or intra-institutional programmes that can operate as data providers (e.g. different monitoring initiatives among the participant organisations). Robust platforms tent to be demanding in terms of system requirements. This point should be managed in a way that robustness does not entail lack of functionality. An aspect that facilitates the dataflow between uses is that geo-referenced information is available for the different scopes of management (e.g. water body, municipality and grid).
- *Plurality.* The system should be able to host very different types of information, both in terms of file formats (e.g. datasets, GIS, multimedia) and quality of data. This involves data from scientific sources and routine programme monitoring, but also data from citizen science. Opening the strand to all kinds of information indeed increases the risk of mixed messages, a fact that has been already pinpointed by the scientific world. Yet only by bringing all these types of information together it will be possible to compare them and to assess their reliability and suitability to inform policy decisions.
- *Timely data availability.* Access to up-to-date data demands both easy incorporation of new data and enabling timely access to the information. Therefore, both data entry and data export formats must be considered from the moment when the information system is designed.
- *Multilingual*. The information hub should be accessible in the languages that better fit the users. As international communication is a need, the availability of the information in English besides the local languages is highly advisable.

The contents of potential 'Catalan AIS information hub', with the characteristics that have been just outlined should not replicate information that can be easily found in other similar initiatives. Instead, concrete information that can be useful for underpinning regional and local management encompasses:

- Recognisable contact points within the different participant organisations.
- Information about local distribution of species available per (and within) water body and municipalities.

- Glossary of terms according to regulations in force and links to the regulations themselves.
- Regional and local planning schemes and protocols in case of contingencies (detection of new species, new detections of species already present).
- Communication programmes and links with initiatives of citizen science.
- Guidelines for preventive management of pathways and dispersal vectors, both from a sectoral and from a spatial point of view.
- Battery of tested eradication and control measures, not replicating information that already exists in other databases, but compiling regional tested practices.

Table 57 Possible structure of a regional hub on IAS

Source: Adapted from East / South European network for IAS (www.esenias.org)

Item	Public (open)	Public (interactive)	Internal
Species database	Species list Species fact sheets Identification tool Distribution map (water body, municipality, grid) Photo gallery	Search (e.g. by location, by species group, by pathway) Risk assessment tool Citizen's science area	Geo-referenced databases (application for data entry, moderation, export) Risk assessment tool (metadata)
Territory	Pathways and entry points Hotspots Vulnerable areas (e.g. key biodiversity areas, key infrastructures) Facilities for AIS prevention and control	Search facilities	Geo-referenced databases (application for data entry, moderation, export)
Experts and practitioners	Public managers (per sector) Institutions (research, education) NGO (e.g. environmental and sports) Private (economic sectors) Working groups	Search experts (by location, by taxonomic group, by type) Register as an expert Contact	Detailed contact info Mailing lists
Projects	Projects by country Project by species	Search project	Common project area
Legislation and guidelines	Legislation Competent authorities Biosecurity guidelines Codes of practice Glossary of terms	Search legislation and guidelines	Internal operative guidelines
Management	Risk assessment protocols & Risk management plans Best management practices Action plans (species, sectoral, site-specific)	Search management options	Internal protocols (emergency, sampling, communication)
Resources	Scientific publications Reports and documents Newspapers Education materials Video / podcasts	Search resource	Internal documents / minutes Draft documents
News	Species alerts News Announcements (e.g. campaigns) Events (meetings and conferences)	News alert	Non-confirmed species alert
Links	Links (to databases and programs at the global, international, national, regional level)	Search links by contry	None

4 Tackle the invasional meldown

Aquatic bionvasions are interlinked and should not be managed separately from each other. On the one hand, they are all related to complex processes that impair the biological quality of the river in an uncontrollable manner. On the other hand, the social processes behind the invasions are also complex

and can be hardly manipulated in isolation. As shown in the previous chapters, some stakeholders benefit from the presence of given species, like an introduced fish, but its presence is possible due to the prior abundance of other damaging alien species and its use is likely associated to the introduction of new species that causes impacts to other stakeholders.

The hypothesis of the invasional meltdown surged within the field of invasion biology as an extension of the idea of mutualism. However, it is also useful as a metaphor of the tangled socio-ecological drivers that need to be addressed to prevent damaging invasions.

Inaction should not be the corollary of the invasional meltdown since efforts to control the existing species are valuable to lessen the likelihood of future invasions. Thus the identification of key facilitative interactions should be a first step to prepare responses in an integrated way, starting from risk assessment. For instance, the interactions between AIS and their host ecosystems need to be properly formulated. Then, then measures need to be deployed in a way that not only the impacts of a particular species, but the chain of changes linked to that species can be prevented. A fish like *Alburnus alburnus* is considered as a low risk species in Catalonia. However, the bioinvasion chain described in this dissertation relates it indirectly with the introduction of a damaging high risk species (*D. polymorpha*). Thus control measures for this species would be justified based on precautionary reasons, to prevent the tangled chain of changes that follow this introduction.

This idea should pervade the different policies developed on the area, especially water management, environmental protection, tourism development and agriculture. This requires a clear expression of political will on AIS control in each of these policies, though integrated decisions, regulations, access to information and resources availability.

5 Confront the common enemy first

How to disentangle the invasional meltdown? The socio-environmental interactions that drive bioinvasions often operate at levels beyond the regional policy maker's capacities for action. In this context, the goal of controlling non-conspicuous AS may not be a priority for many groups, regardless of the role that such species have in the general bioinvasion issue. However, some AS have the power to be mostly agreed as unwanted events. In such cases, the argument of the common enemy may trigger a focal response.

Along the research process, it was noticed that the topics addressed in the debate about these charismatic AIS often went beyond the presence and management of the invasive species itself. The issue 'invasion' seemed a useful topic to discuss other environmental and socio-economic problems that take place in similar scales involving the same set of stakeholders. Specifically, in the case of the zebra mussel, it was easy to use the invasion argument to construct dialogues that otherwise would not have taken place. Invasions were even used to protect the environment or to push forward territorial initiatives that previously were blocked. This is the case of the rejection of the National Hydrological Plan in the Ebro. Other examples are the reorganization of the navigation schemes in the Internal Basins of Catalonia, the restructuring of the fish repopulation system in Catalonia or even the frequent request for an integrated management of water bodies, in particular when there was a strong recreational component involved.

Although the original interests of the involved stakeholders did not change, focussing on the common objective – combating the invasion of the zebra mussel – facilitates the exchange of information and mutual learning. This does not guarantee the reaching of agreements among the stakeholders but it

breaks deadlocks by offering a good reason to initiate dialogues. Common enemies are usually high risk species, but not all high risk species prompt join responses. The same as in the case of emergency situations, mentioned above, the 'common enemy' should be employed as a triggering factor, but integrated policies should derive from there. This bring us to the next recommendation.

6 Focus awareness from the anecdotal to the integrated discourse of management of water quality

In Spain, the invasion of charismatic species such as the zebra mussel or the apple snail has produced a better public understanding of invasive species as an environmental problem. Although this awareness is related to the economic impacts of the species, public actors and scientific advisors highlight the opportunity it gives to strengthen the discussion on the role of biodiversity in ensuring a good water quality. Good ecological status (or potential) of water bodies is bounded by physico-chemical, hydro-morphological and biological quality elements that deviate only slightly from undisturbed conditions. The presence of the some alien species has an effect on such elements and thus entails a menace for fulfilling the quality targets of the WFD. The particular effects of the species are poorly studied at the site level, but indices such as IBPR can identify areas where there is a risk of non-compliance. As demonstrated above, biopollution risks indices are not totally redundant with the indices used to assess biological quality elements.

There is a need of an inclusive social dialogue about river quality and river use management. This supports the idea that engagement with biodiversity must be comprehensive and not confined to the rare and threatened, a message repeated by some global conservation initiatives.

The role of invasive species in the impairment of river quality might be more apparent if the integrative frameworks, such as the ES approach, were used to explain the AIS impacts. Note that in this way, the benefits of the species, such as the recreational value of the presence of alien fish would emerge as a relevant factor to be taken into account in their management. But the consideration of the different effects may promote an open dialogue about the implications of such management at the territorial level. At the same time, this would support research on the study and communication about the real ecological impact of fish invaders.

7 Manage at the most appropriate scale and encourage local agency

Despite the fact that in Europe governmental organisations with responsibilities of territorial management (e.g. biodiversity, water management planning) are mostly are the regional level, research about the role of regional agencies in AS management has been neglected. This is, in fact, a key level for management, as it has been highlighted along the dissertation. Another key insight has been the relevance of underpinning the capacities for local response. According to the above analysis, the performance of the local agency depends on the opportunities of stakeholder groups to access information, past resistance movements against external influences, social networks and polarization of coalitions, among other factors. Local agency performance is relevant for inter-scale interactions.

While stating this, there is awareness on the risk of the 'local trap', a problem highlighted for studies in political ecology that seem to assume that action at the local scale result in more desired social and ecological effects, while this is not inherently true (Brown and Purcell, 2005). In face of this, reinforcement of local agency would strengthen the local stakeholders' capacity of coping with unwanted external influences. Larger-scale driving forces of damaging bioinvasions are one of these undesired influences. The local agenda can be improved if water quality (including biodiversity) and not

only water quantity becomes the centre of debate. Local stakeholders are prone to participating in the integral management of water bodies (planning, monitoring and surveillance) if they perceive that their proposals are really implemented. Biodiversity can be one of the focuses of this kind of participatory planning. Thus, the inclusion of stakeholders in the process of designing, implementing, and monitoring management responses to biological invasions is recommended. This does not mean to delegate all the responsibilities of AIS control to the local level. Regular interaction and mutual surveillance on the obligations at the different management levels is required.

Areas where enabling local agency for controlling bioinvasions involve local planning for the prevention and control of AIS, monitoring, information campaigns and the implementation of eradication and control campaigns in coordination with regional authorities. A pilot experience in the UK to test strategic approaches to freshwater non-native species management (Taylor and Lycett, 2008) entailed a process which seems to be adequate to replicate in the case of water bodies in Catalonia. It involves the following stages: 1): Identification of an appropriate scale at which to run the initiative; 2) Identification of and contact of relevant stakeholders; 3) Organisation and facilitation of workshops; 4) Drafting targets and actions; and 5) Ensuring engagement and sustainability of the process.

Empowering local agency often requires regulatory adaptations in relation to the larger-scale framework, distribution of funding, training and small-funding allocation (e.g. for the development of prevention facilities). Initiatives that aim for a self-organised, but integrated, local development (as in the case of planning recreational initiatives for specific reservoirs) offer great opportunities for AIS prevention and control based on local agency.

8 Engage in networking action at all management scales

A main insight from the previous chapters is the multi-scale nature of drivers and impacts of aquatic bioinvasions. In the same line, there are also different initiatives that respond to the problem, from the international to the very local one. As advised above, orchestrated action is a key element of responses against aquatic AIS. However, there are very different ways to approach coordination, from the most hierarchical to the most horizontal one. A way to prevent replication of efforts and enhance autonomy between the different parties interested in AIS control is to articulate the inter-organisational ties through networking action (NA).

The advantage of networks in relation to other types of organised response is that they facilitate the participation of different types of actors, at different scales (and across scales), more spread in the territory and with faster time-spans in terms of response (that in turn can be more adjusted to complex assemblages of drivers and potential impacts). Thus NA arguably offers a cost-effective and enduring way to organise responses as they it brings together expertise and resources from multiple stakeholders. NA not only provides opportunities for collaboration but also promotes connections between actors with differentiated skills who were previously unaware of their collaboration potential. The point is to stimulate discussions and agreements on common action in the respective scopes of competence.

In the case of bioinvasion management, the idea is not to create viral networks but organised ones, based on different roles can be performed (leading, being part of data providers/managers, being informed, etc.). An organisational design is therefore needed in order to identify areas or responsibility, potential overlapping areas and even intervention gaps. The starting point can be a simple database of contacts, which can be expanded based of snowball engagement. Some actions may be favoured by more extended networks (e.g. communication, citizen's engagement in prevention and monitoring,

volunteering in control actions), while some others may require deepening the networks (e.g. coordinated enforcement campaigns involving a core group of managers).

Networking tools may involve regional stakeholders' meetings (including scientific meetings and conferences), workshops, training courses, seminars and webinars and the creation of virtual fora, dissemination and use of the social media. Exploring NA opportunities and using effectively the AIS hub outlined above are two sides of the same coin.

9 Tackle uncertainty with diverse appropriate methods

There is a variety of available methods to tackle uncertainties around bioinvasions, involving both qualitative and quantitative approaches. Information sources and methods should be used with an open, pluralist mindset, picking up the ones most befitting each specific decision context.

Along the thesis, some specific elements of knowledge gaps or 'uncertainty' have been unveiled, most of them based on the empirical context. Building on the scheme proposed by (Stirling, 2010; Stirling et al., 2007), such elements have been classified in four types: risk, uncertainty, ambiguity and ignorance. Note that in this scheme, indeterminacy (*sensu* Wynne, 1992) is considered a particular form of phenomenological ignorance, when intrinsic properties of the world are hidden to the observer. 'Ambiguity' corresponds to what has been called 'ambivalence' in other sections of the thesis. The different items are presented in **Table 58**, together with analytic and management methods that seem appropriate to deal with them.

A general recommendation is to respond to knowledge gaps with an adaptive management founded on humility and enhanced transparency. More specifically, and summarising insights from the dissertation it is possible to distinguish some advisable strategies for each one of the situations depicted in in **Table 58**. Thus, under a **risk** condition appropriate tools involve those dealing with risk assessment, communication and management, estimation of BP&BC indices, and simulation. In the case of **ambiguity** tools that enable dialogue and deliberation at a public scale are advisable, together with those that help to increase awareness about the complexity of decisions on introduction and management of AS. An example would be to explain the difficulties of dealing with a species isolated for the effects that this species may have in increasing the potential for other invaders to establish.

Both in the case of uncertainty and ignorance, acquiring new information (either about the attributes or outcomes of a certain bioinvasion or about probability of their occurrence) may be a way to deal with knowledge gaps. Resources like enhanced monitoring, added knowledge through research, or transdisciplinary and inter-stakeholder exchange of ideas may help to this purpose. Adaptive management is recommended in both situations. In the case of **uncertainty** this can be underpinned with scenario development and scenario-based modelling. Meanwhile management in conditions of **ignorance** can be supported in expert assessment and qualitative RA, acceptance of sources of information alternative to traditional scientific information, societal and institutional learning, design of shock scenarios and public deliberation.

Knowledge development may lead to changes in the way how a given question is situated in relation to 'uncertainty'. A traditional approach in invasion biology has been to underpin datasets and methodological processes to produce more accurate risk assessment; that is, moving from a condition of ignorance to a condition of risk. However, more and more scientific-informed opinions speak in support to the use of more integrative tools, like scenario development, in conditions of real uncertainty. Managers have been familiar with the issue of ambiguity and just recently this issue has started to be addressed in scientific research.

Table 58 Uncertainty in AS management

Note: Each sector reflects a type of knowledge gap. The arrows point to appropriate methods for gaps listed immediately above.
Source: Own elaboration

		Knowledge about outcomes	
		Less problematic	**More problematic**
Knowledge about probabilities	**Less problematic**	**Risk** Introduction of highly invasive species Spread of species already present in the territory, based on the match between the species and the characteristics of the territory Vulnerability of host ecosystems (e.g., seabeds, river sections, reservoirs) Impacts in highly vulnerable areas (.e.g. fixed / non-adaptable infrastructure) ***→ Risk assessments / BC&BP*** ***→ Simulation*** ***→Risk communication & management***	**Ambiguity** Values of 'nativeness' vs. (ecological and socioeconomic) functionality of AS Conservation trade-offs in the case of radical measures for the control of AIS Economic trade-offs due to restrictions to management Diverging views about the effects of a specific AS Bioethical conflicts on the elimination of AS ***→ Public deliberation on and negotiation of management actions*** ***→ Awareness and communication of complexity (e.g. bioinvasional meltdown)***
	More problematic	**Uncertainty** Arrival of species related pushed by complex socio-environmental drivers Intensity in the operation of some of drivers (actual traffic of vehicles, actual number of anglers …) Actual distribution of the species during their lag phase Effectiveness of the surveillance grids / protocols to detect new arrivals Key facilitative interactions between AS Attribution of 'potential' impact for some species Existence of time lags between information needs and information availability ***→ Enhanced monitoring*** ***→ Additive knowledge increased by research*** Ridge between the 'not-invaded' and 'invaded' condition (ecologically and from the management point of view) Degree of tolerance of AS in in undisturbed conditions of water bodies ***→ Transdisciplinary / Inter-stakeholder deliberation*** Prevalent administrative and normative framework for the control of AIS Prevalent type of water management Prevalent strategy for AIS management Magnitude / type of impacts dependent on management decisions or social choices ***→ Scenario development & Scenario-based modelling*** ***→ Adaptative management, information)***	**Ignorance** Acknowledged information gaps in available datasets and lack of biological, ecological and socio-economic knowledge about: - marine species, in particular marine macroalgue - driving forces (including pathways) associated with the less studied species and pathways of introduction of some species in the past - impacts of fish species, and alien species in general - effects of AS in native biota; effect of AS control in biota - benefits of AS - difference between high invasiveness potential and real invasive performance - interaction between AIS impacts and other stressors - irreversibility of the transformations the river ecosystems due to AS ***→Enhanced monitoring*** ***→Additive knowledge increased by research*** ***→ Scientific cooperation*** Poor knowledge of ecological attributes of some species (e.g. algae) leads to incomplete logic models for the risk analysis of species Lack of predictive value of risk assessments (false negatives) Information about the species unavailable to proceed to risk assessment ***→ Expert assessment and qualitative RA*** ***→ Methodological development / Independent testing of the method / analyst*** ***→ Acceptance of alternative information sources*** ***→ Adaptative management*** Salient knowledge about aquatic AIS of concern is largely available (e.g. *Proclambarus clarkii*, *Cyprinus carpio*, *Carassius auratus*) but this has been poorly accounted for in normative development (e.g. Spanish AIS catalogue; regional angling regulation). This is a form of institutional ignorance that should be progressively redressed opening the legislative process to truly transdisciplinary enrichment. Information about AS distribution and impacts should be publically available and interconnected thus preventing societal ignorance due to poor data availability through societal learning. Occurrence of illegal fish translocation, malicious deliberate releases ***→ Transdisciplinary / Inter-stakeholder dialogue*** ***→ Societal & institutional learning*** ***→ Design of shock scenarios***

10 Set an agenda for management-focused research

Science and management are different domains and merging them should not be aimed at. Very effective practical and corporatist barriers prevent this from happening anyway. However, it is desirable that both entangle their concerns in a way that new research sheds light precisely on the issues where the need to tackle uncertainty in is more critical for management. Although this goes against any presumption of separation between science and policy making, it also entails a defence of normal science, which has made significant contributions to AS management in the past, as long as the scientific process enables mechanisms to listen and to respond to collective and institutional calls for engagement.

In fact, scientists already play a prominent role in management of alien species in Catalonia. The responsibilities of AIS management are diffuse from and administrative point of view and it has been thanks to the warning from the scientific domain that there has been a push towards integrated intervention. Thus scientists supported planning, scientific advice, and as in the case of the author of this thesis, multi-stakeholders participation in the measures against AIS. The watershed authorities have been developed a network of stable collaboration with several research centres although these were rather dependent on the availability of financial resources to maintain the joint activities.

Dependency on funding is not the only element that prevents a better integration of scientific developments in the management of AIS. In order to advance towards a more reflexive science, some desirable properties of the science-management nexus would be the following:

Principles

- Mutual respect and understanding of the diverging objectives of science and policy & management.

- Reflecting on doing. The transformation of management concerns into research priorities is contingent of the interaction of the researchers with the specific contexts and processes that generate the policy concern. Only facing and solving specific problems will be possible to trigger an innovation process that will provide more accurate insights for management that a priori reflections. Thus certain issues could be internalised as the focus of research, with a conscious awareness of the implications of the use of the scientific outcomes, in terms of scope and limitations.

- Communication and dissemination of findings. While being crucial, seeking new information and knowledge is not the only type of cooperation between scientist and managers. Such knowledge also needs to be offered in formats that are available and comprehensible to the users. This means, in particular, to find effective ways to disseminate scientific results outside the scientific literature.

- Preventing replicated efforts and focus efforts on data gaps. There are identifiable gaps in the existing datasets and lack of biological and ecological knowledge of some AIS (see above in **Table 58**), while other species concentrate disproportionately high scientific attention. A dialogue on this issue between managers and scientist could help to optimise resource allocation for research.

Table 59 Areas for enhanced science-management interaction

Source: Own elaboration

		Policy to science	Science to policy
1	Visualise the goal as a moving target	Listing of priorities for management Identification of policy questions and sensitive issues interlinked with AIS management Clarification of the institutional and legal frameworks for action	Providing evidences of the need of controlling bioinvasions Better understanding of ambivalence. In this process, not only natural sciences can be supportive. Social sciences play a crucial role in the consideration of diverse (and possibly, divergent) social views
2	Improve coordination by all means	Proposal of a discussion agenda for scientific boards Effective consideration of scientific insights into policy action	Scientific advice in policy events, participation in scientific boards in support of management Training
3	Create an information hub at the regional level	Information sharing (from monitoring programmes, citizen science initiatives, etc.) Hosting and managing the nodes of management within the hub	Information sharing (from scientific research) Hosting and managing the nodes of scientific research within the database
4	Tackle the invasional meldown	Identification of processes of concern that can be hiding an invasional meltdown	Identification of key facilitative interactions between AS
5	Confront the common enemy first	Pinpoint 'common enemy' candidates from the administrative point of view'	Pinpoint 'common enemy' candidates from the scientific point of view
6	Focus awareness from the anecdotal to the integrated discourse of management of water quality	Local distribution, abundance and impacts of AS through routine monitoring programmes	Although the assessment itself must be guide a systematic organisation of knowledge, and therefore, can be considered as a scientific endeavour, an agreement with stakeholders on the reasons why a particular species is considered as a hazard will benefit both the comprehensiveness of the analysis and the use of its results in policy making. AS and water quality
7	Manage at the most appropriate scale and encourage local agency	Engage local stakeholders in the identification of research needs related with management activities	Integrate local stakeholders in concrete scientific activities (through dissemination, training, monitoring)
8	Networking is a crucial element at all management scales	Designating a board of scientific advisors	Play a role within the advisory board of the network Data providers Long term research
9	Tackle uncertainty with diverse appropriate methods	Pointing out species that are problematic from the management point of view Implementation priorities	Improving knowledge on AS impact (impact of 59% AS listed in Catalonia has not been evaluated) Methodological development for the study of ambivalence

Strategies

Strategies to underpin reflexive science entail creating areas of reflection for managers, offering spaces of intervention to researchers and promote innovations through the interaction between both researchers and managers.

a) Provide spaces of reflection to the managers

- Public organisms are often present in research initiatives but their participation is restricted to be supporting institutions or, in the good times, funders of applied research. Public managers have the technical capacities and should participate in research projects as actors of innovation and not just as its final users.
- Systematization of management experiences (failures and successes) should be done under a regular basis, and communicated to other organisms in charge of AIS management.

- Internal seminars of for knowledge sharing should be organised, as a part of the regular training and technical update of public officers.

b) Provide spaces of action to the researchers

- Faced with concrete experiences of management, scientist can more easily frame their problem choice. This facilitates that the priorities of research are motivated and organised with independence of a compromise of funding.
- The contact of researchers with concrete spaces of management action also allows to work beyond the niches of the specific disciplines, finding ways to employ disciplinary knowledge in innovative ways and to encourage transdisciplinarity in the way how the scientific agenda is set up.

c) Provide spaces of interaction and cooperation between scientist and managers to enhance innovation

- Joint discussions on core issues in management guide scientists in their problem choice, pinpointing socially and institutionally relevant uncertainties.
- Stable networks of collaboration, sustained by setting up *fora* and webinars.
- Joint seminars by technical staff / workshops / campaigns.
- Openness to build on citizen science and other forms to connect scientific outcomes to the public at large.

As an example of the benefits from this two way cooperation, areas for enhancement of the policy-science relationship are presented in **Table 59**, according to the management guidelines explained in this chapter.

Themes

Generally speaking, all the topics presented in **Table 58**, on the uncertainties for the management of AIS can potentially become research problems. More specifically, some topics have appeared frequently in the interaction with the stakeholders in relation to important topics for management-oriented research.

- Knowledge about species impacts is of particular interest. The impact of 59% of the alien species in Catalonia has not been evaluated yet. In part for this reason, management focuses on the species that are better known and so does the public attention and demands to the policy sphere.
- Understanding of the drivers, given the current trends and plausible developments, together with information about donor environments should improve knowledge about entrance of new species.
- Both the evaluation of impacts and the risk assessment should improve in relation to the matches between the species and the host environments, beyond dealing with the species individually.
- Understanding of facilitative relations between species and elements that help to prioritize territories and groups of species of risk.

Final remarks of the chapter

This chapter has offered ten general recommendations for organising responses to aquatic bioinvasions. While the recommendations can be generalised to a certain extent, they have been informed by the contents of the dissertation, and therefore they are conceived to suit the empirical context for which they have been formulated.

The 'Decalogue' does not reproduce traditional schemes for the management of AIS but stems from key findings from the dissertation. In this respect, it can be considered as an empirical conclusion to the thesis. In order to close this document in a more traditional way, a final chapter with conclusions is presented next.

Conclusions

From the theoretical point of view, this dissertation has brought together the literatures of ecological economics, conservation and invasion biology, water management and uncertainty studies. Empirically, the relevance of the topic has been highlighted in relation to a major pressure in global biodiversity impacting particularly freshwater ecosystems, and a priority of environmental and water management that is also a rising social concern.

The dissertation has been framed within a reflexive model of science, which entailed engagement with the observed processes. Thus analyst's influence has gone beyond the construction of a set of meanings, since it has also shaped parts of the agenda and somehow the evolution of the socio-environmental phenomena under study. Many of the research activities were product oriented, this encompassing the design of informative campaigns and training courses about the impacts and prevention of the zebra mussel spread, the promotion of new research activities for its genetic identification, the monitoring of the evolution of the species, defining criteria for declaring a new colonized area, the identification of impacted actors and sectors and the development of mitigation measures, among others. Along these activities, new information was created and acquired significance, thus contributing to a more complete understanding of the invasion processes. At the same time, the research was still based at university with complete freedom to include topics and approaches that are relevant for such studies.

The use of the DPSIR framework has been useful to organize the information available from direct and long-lasting contact with the research topic. However, the DPSIR scheme has not been used for analytical purposes since it faintly represents processes occurring at various scales, or processes that are understood different by diverse actors. The decision was then to employ the DPSIR categories for presenting the results, but organizing the answers to the different research questions using different approaches and methods. The following pages summarise the main findings of the dissertation, organised according to the blocks of research questions presented in the introduction.

Responding research questions

a. Management context

Chapter 1 has described the *problématique* of AIS management in aquatic ecosystems. This has been done using the case of Catalonia at two scales, the regional level and the local level in two study areas. Some references to the situation in the Spanish and EU contexts have been also included.

At the Catalan level, the changes in management have been illustrated with some emblematic cases, namely the recent history of management of exotic marine algae, freshwater fish and the apple snail. In general, the response to aquatic bioinvasion has shifted from the interest in some high-impact AIS to a more integrated approach to the state of aquatic ecosystems. In Catalonia, the clearest manifestation is the way how the issue of IAS has been integrated in the implementation of the WFD, which puts the control of AIS hand in hand with the improvement of water quality. This integration is examined in detail by first time in this thesis. Such integrated interest though is dependent on changing political priorities and has been impaired by the effects of the economic crisis on public funding. However, there is firm scientific attention on the matter for the last fifteen years. Tracing the appearance of these taxa in the press since the 1970s until 2013, it has been also possible to demonstrate an increasing social awareness about each one of the cases, and also about the issue of bioinvasions in general.

The situation of AIS management has been also described in-depth for the case of two aquatic species (*Dreissena polymorpha* and *Silurus glanis*) in two different study areas of Catalonia. This helps to better understand the concrete management processes and how they are influenced by different administrative and socio-economic conditions. The two studied areas have a strategic role in the provision of crucial material benefits (energy supply and water supply respectively) for users outside the areas. That provision required the construction of dams that had a double and intertwined effect. On the one hand they created a new socio-economic space for actors interested in recreational activities. On the other hand, they enabled transformation in the biotic communities, facilitating the establishment of alien fish that fit well with the altered hydro-morphology. The levels of profitability needed to sustain economic activities related with sports angling would hardly be obtained based on the previous species, less attractive for the anglers. Thus, to certain extent, the two effects are mutually required.

Aquatic invasions transform irreversibly and are also result of the transformation in what – paraphrasing Paul Robbins – can be considered a 'human preparation of the (water)scape'. The change in aquatic communities is not only a matter of biological change, or in the functionality of aquatic ecosystems. It is also accompanied by deep socio-cultural and economic changes. When a dam is built and a new fish community replaces the previous one, new economic activities can indeed flourish, but the previous socio-cultural context is irreversibly modified. Rivers have suffered a silent colonisation that has eroded traditional ecological knowledge on aquatic species. Efforts to restore ecological quality may not reverse this situation. Stakeholders' engagement fosters management actions. But it also opens up conflicts on the criteria that are relevant, on the scale to be adopted, and on the very definition of invasive species themselves.

In any case, water management and the idea of improved water quality determine the perception of both species (zebra mussel and European catfish) as unwanted. However, eradication is impracticable in the two analysed cases. Technical reasons in the case of *D.polymorpha*, while economic and social reasons in the case of *S.glanis*, rise as barriers for eradication. In particular, there is agreement in the need of considering European catfish as a species that should be controlled. However, the economic interests related to angling in one of the areas (the Ebro River) are high enough to have percolate the legal normative, becoming *de facto* a zone where the species has the consideration of an asset for angling practices rather than a species to be controlled for the improvement of biological quality of the river. Although introduction of alien fish species is forbidden, the increasing number of records of *Silurus glanis* shows that new translocations are still taking place outside the Ebro River.

At the same time new records of zebra-mussel spread evidence the limits of the measures applied so far. The invasion of *Dreissena polymorpha* is agreed upon as a damaging process that should be controlled. This alien mollusc has received a great deal of public attention and resources for management. Still the invasion has advanced unstoppably in the Ebro. Although the colonisation has been confirmed in other areas of the IBC, it has not yet been detected (to the best author's knowledge) in the Ter River, despite the fact that the invasion drivers operate intensively in that area. Alarmingly, the restrictions to certain activities that contribute to the spread of this species (angling and navigation) have been recently relaxed related with the interest of promoting economic activities.

b. Driving forces

When policy action is required to manage environmental change, there is a need to characterise driving forces in terms of the immediate possibility of intervention to reach desirable scenarios. Thus, identifying driving forces seems to be necessary not only to understand the processes encompassing biological

invasions but also to generate policy-making initiatives. In **Chapter 2**, driving forces of biological invasions have been analysed under two different approaches. Fist generic driving forces of biological invasions have been examined through literature review according to a framework that has allowed distinguishing several levels of response. First, there are drivers in relation with management practices (such as transport, trade activities, changing practices of flora and/or fauna management or the access to available options for invasive species control. Second, there are drivers related with the policy level, such as trade policies, agricultural policies, political transformation, environmental policies and all the regulatory changes that accompany such policies. Third there are drivers related with ideologies and lifestyles encompassing global and domestic economic and social developments, emerging social interests, changing perspectives in environmental protection and all that has to do with developments in knowledge and information. Finally human population dynamics and global climate change were considered as important driving factors that should be considered as exogenous in the short term.

This level of analysis provides a rich understanding of the different aspects that can be taken into account when preparing responses to invasion processes. It also helps to distinguish driving forces in relation to the easiness to translate management decisions in concrete desired societal behaviours. Developing communication activities with stakeholders, based on their views about the plausible evolution of the key-drivers indicators, may enhance the policy strategy. Attention to the different levels of drivers and their interactions will broaden the system of analysis and favour a deliberation process where different stakeholders should intervene in the discussion of responses.

In fact, the linkages between the different types of driving forces are difficult to establish at that generic level. In this respect, it has been valuable to study the concrete cases of the *D. polymporpha* and the *S. glanis* invasions in the two specified research areas of Catalonia. For the issue of the driving forces, this was done using participatory methods in a post-invasion context.

Besides the identification of the specific driving forces of each one, three findings emerged from this process. The first one is to conclude that the invasion of the zebra mussel in Catalonia is part of what the literature has called an 'invasional meltdown' where a chain of alien species establish facilitative interactions among them. In this case, it is revealed that these interlink is not reduced to a particular form of mutualism (ruled by ecological relations), but extends to the socio-economic drivers that pushes the different invasion processes. This opens the door to study invasional meltdowns also as a matter of concern of political ecology, trying to establish the type of socio-ecological transformations needed to sustain this process and the outcomes, in terms of the distribution of costs and benefits involved.

A second (and related) finding was disentangling these interconnected set of drivers, coming back to the organising framework at the beginning of **Chapter 2**. In support of the use of a political ecology perspective the relation between the introduction of damaging AIS with recreational and angling-related practices based on alien fish predators triggers a discussion where, on the one hand, there are the social and economic benefits that these activities provide to the area and in the other hand there is an process of ecological impoverishment of the river communities. The chapter then highlights that the ecological homogenization is a result of a utilitarian, market-based view of ecosystem management.

Finally, the third finding consists in establishing a hierarchy of driving forces, based on the views of the local stakeholders, where less relevant factors are distinguished from givens (relevant and predictable factors), and from key uncertainties (relevant and unpredictable factors). Seeking a generalisation of these results, this chapter also helps to helps to classify driving forces for the case of zebra mussel and

proposals that are coherent with these different types of risk factors, uncertainty factors and ignorance factors.

The final part of **Chapter 2** integrates both ways to understand driving forces stating that, while multi-level action (regarding management, policies, ideologies and lifestyles) is required, local agency matters (a lot), regarding AIS management. According to the analysis done, the performance of the local agency depends on the opportunities of stakeholder groups to access information, past resistance movements against external influences, social networks and polarization of coalitions, among other factors. After examining several these constituents, it is possible to conclude that Ebro people have been able to activate local agency and react to recent unwanted initiatives in their territory, despite the multiple transformations of the river. Local agency performance is relevant for inter-scale interactions. Therefore, any management measure should rely not only be informed by the plausible developments that are relevant at larger scales, but also be consistent (and not be resisted) by the local contexts.

c. Impacts

Chapter 3 offers different insights on the consideration of impacts of aquatic AIS. This is done, first, by presenting a framework to organise impacts of biological invasions that distinguishes impacts caused directly by the species from those that stem from the type of responses to the invasion. This framework relies strongly in the use of the ecosystem service approach to understand diverse types of effects and their interrelation. The use of the ecosystem services (ES) framework has proved to classify impacts and depict them according to a set of suitable indicators. As a consequence, the inherent complexity of bioinvasions is simplified in a way that it can benefit policy-making in the three ways: communication, monitoring and assessment. The approach also reveals the issue of ambivalence of AIS, that is, that species may generate benefits along with the damages caused.

After this, the framework was used to analyse direct impacts of AS from different taxonomic groups present in aquatic ecosystems in Catalonia, using data from the ExoAqua information system. This entailed a laborious classification of 356 species according to the type of impacts in ES provision, which has done for the first time for the Catalan case. More than 75 percent of the listed species in the ExoAqua database lack a data for characterisation of impacts, either because the existing studies are not conclusive in terms of the impacts caused or, more frequently (58 percent of the listed species), because this impact has not been evaluated. This offers an important insight in terms of the challenges for scientific research about AS. Focussing on the species that count on information, plants, followed by fish and invertebrates, are the taxonomic groups more frequently related with AS impacts. Regulating and supporting services are the most frequent impacted services although they are unnoticed for the general public. This analysis refers to the number of impacts registered, and not to the intensity of the impacts. This explains that impacts in provisioning services or the incurrence of control costs, while much less frequent, tend to be more conspicuous for the public at large.

The analysis identifies 17 species that are associated to monetary costs (either damage or control costs). It also helps to pinpoint 12 AS present in Catalonia that have proved impacts, according to the literature, in different dimensions of water quality, either physico-chemical (e.g., increased turbidity or increased nutrient concentration), biological (e.g. changes in phytoplankton or alteration of invertebrate communities) or hydro-morphological (e.g. reduced instream flows or destabilisation of sediments). All these elements are at risk due to the proliferation of AS in the Catalan rivers. At the same time half of these species of concern for the improvement of water quality are related to monetary cost.

Again in order to get better insights about the impacts at the local level, the effects of *D. polymorpha* an *S.glanis* have been classified using the framework presented at the beginning of the **Chapter 3**. A variety of impacts are presented and, in the case of the zebra mussel, a monetary estimate of impacts during the period 2001-2008 is presented, based on direct research done in the area. Results point out to annual cost of ca EUR 1.4 m per year by the end of the assessed period. These calculations are consistent with estimates from the water authority in the Ebro, but more precise in terms of the distinction between damage and control costs.

Gathering information from the invaded context was also useful to get orders of magnitude of costs that would be then use to generate estimates of the potential monetary impacts of the zebra mussel in a non-affected area, the Ter River. These are calculated using different management scenarios that, in fact, are described in the next chapter. Here, the impacts are calculated based on a simple methodology proposed also in this thesis. While the accuracy of the estimates may certainly improve with more direct research in the non-affected area, the calculations still deliver highly valuable information for management.

Thus, the estimate of the potential damages offers ranges of costs for three possible scenarios('No action', 'Mitigation', 'Adaptation') along four stages of the invasion process that are relevant for management ('Pre-Invasion', 'Pre-alert', 'Immediate post-invasion' and 'Persistent post-invasion'). The possible distribution of costs between the main types of actors involved, along the invasion process is also outlined. In general, the hydroelectric sector and water supply managers would be impacted sectors in all scenarios, followed by sector involved in irrigation.

Accordingly, all actors incur costs during the post-invasion phase, but these costs vary remarkably according to the management scenario. Thus higher costs bore during the pre-invasion and pre-alert stages entail more than proportionate savings during the post-invasion contexts, particularly in the long run. The extreme cases are the 'Do nothing' and the 'Adaptation' scenarios. Using data from the lower range estimates, 'Do nothing' means no costs during the pre-invasion stage, while 'Adaptation' may mean to invest up to ca EUR 0.7 m. Then, if the invasion eventually occurs, the costs can be up to EUR 1.3 m per year in a context of inaction, while 'Adaptation' would mean annual costs lower than EUR 0.1 m. These conservative figures (in orders of magnitude comparable to the ones in the Ebro River) have a more than a twofold increase if the higher range stimates are used instead.

After the different approaches to the assessment of AS impacts, it is possible to conclude that AIS impacts are multidimensional, ambivalent, often unknown and context-dependent. This entails challenges for management-oriented assessments. In particular, two essential traits to have in mind are the potential and limits of monetary assessment of impacts and the central role ES have in facilitating coherent responses to aquatic bioinvasions.

d. Preparing responses

Chapter 3 brings together three different approaches to address uncertainties that emerge while preparing responses to invasion processes. Thus it expands on the use of such approaches for the preventive management of AS in Catalonia, with a particular reference to the use of their use for the management of the zebra mussel and fish invaders.

The first approach is **risk assessment**, a tool favoured by managers in charge of tackling invasion processes. The chapter reviews the existing experiences in what aquatic bioinvasions concerns, and explains the state-of-the-art situation in Catalonia. Catalonia counts on a relatively advanced level of implementation of risk assessments of aquatic AS, but this does not necessarily infiltrates management

decisions. Two developments illustrate to this situation. First, the creation of the index MZ-Cat, developed for the case of the zebra mussel, entailed an advanced methodological approach that distinguishes elements of introduction and elements of establishment. The susceptibility to the invasion of most of the water bodies assessed goes from 'high' to 'extreme'. This is consistent with the detection of zebra mussel in new reservoirs over time. This vulnerability will increase if prevention measures related to the main drivers of the invasion (angling and navigation) are not enforced or relaxed. Second, 64 species present in aquatic ecosystems count on an assessment adjusted for the regional context prepared together with the existing information system about AS (Exo-Aqua). Nine of the 21 fish species assessed are 'high' or 'very high' risk species but four of them have been matter of exception in the mechanism for AS control within the angling regulation in force.

The section continues arguing the usefulness of pursuing a risk assessment approach for Catalonia. The reasons mentioned involve 1) the convenience of lower-scale evaluations due to environmental singularities and b) the better knowledge of relevant factors such as regulatory mandates and social considerations.

Methodological developments on risk assessment and better knowledge of the species are still required, over all for those where the risk assessment is not conclusive due to information gaps. In respect, the desirable attributes of risk assessment s for a practical support to public policies are finally outlined, encompassing accuracy, adaptability of the method, traceability of results, articulation with systems of early alert, usability of results, disaggregation of results per invasion stage, spatial representation and link to regulatory mechanisms. However, improved methodologies and more information about the species do not suffice for preparing preventive policies if the results of the assessments are not really considered in management.

Chapter 4 continues with a second approach, assessing **BC&BP indices** as an option to integrate AS and their impacts in the ecological status classification of water bodies. This responds to a critical need of testing such indices in relation to their application to the procedures of the WFD, including monitoring. Three methodologies are tested, and two of them (the SBC and IBPR indices) are deemed to be applicable with information available from the routine monitoring programmes for fish species, that is, without requiring additional sampling effort and resources.

The test is done for different periods and using different metrics of AS abundance (density or biomass). Results do not differ markedly depending on the metric used although some nuances are detailed in the corresponding sections, together with the advantages and disadvantages of each methodology. Results suggest less than good ecological status – indicated by moderate and more than moderate biocontamination [biopollution risk] –, in 47 percent [40 percent] of sites with fish communities. There is 82 percent coincidence between the results of SBC and IBPR. In 5.1 percent of the water bodies the results of the indices give a totally different signal in terms of the assessment and compliance, being SBC the most conservative in terms of non-compliance. The test of applicability closes by showing the helpfulness of BC&BP indices for management, regarding the development of preventive measures, allocation of available resources and support to programmes of measures with effects in the biotic communities.

In relation to potential use of the assessed indices as state indicators, the chapter proves that there is a positive (albeit weak) linear association between the performance of BP&BC and a stressor gradient that synthesizes the effect of different pressures in the water bodies in Catalonia. This means that both indices meet the requirement for candidate state indicators. Therefore they could potentially be used as

state indicators if deemed necessary. Different elements of uncertainty interwoven within each method should also be taken into account when selecting state indicators.

Finally, the section on BP&BC indices compares the results of the indices with the performance of the indicators used to assess biological quality for fish, reliant of biotic integrity, which are in fact the ones providing managers with signals to engage in policy measures. The probability of coincident results (ranging between 79-88 percent) is remarkably higher than the probability of non-coincident results (between 12-21 percent). Still, focussing on the non-coincident results, the probability of BC&BP incompliance and biotic integrity compliance ranges between 4-12 percent. This demonstrates that the standard quality assessment fails to completely pinpoint the issue of alien species, hence both types of indices are not redundant. Ensuing remarks are done in terms of helpfulness, limitations and possible improvements about BC&BP indices and their use in management.

The third and final approach to address uncertainty included in Chapter 4 is **scenario development** which compares advantages and disadvantages of participatory and analytic approaches. Qualitative scenarios were developed for the post-invasion context in the Ebro River. Participatory scenario development was based on the cross-over of key uncertainties detected through deliberation with local and regional stakeholders. Key underlying themes in the set of driving forces of aquatic bioinvasions in the Ebro River are the type of water use management and the nature of the administrative response to the invasion. The combination of alternative rationales for each one of these topics configures four basic scenarios that were filled by contents by the stakeholders, and offered an opportunity to frame local situations, accompany social learning, guide local management and, as a corollary of the experience, to provide grounds for larger scales management of bioinvasions.

Another scenario approach tested for the pre-invasion context identified plausible management alternatives and the consistent developments in terms of measures applied and incurrence of monetary impacts. An analytic procedure was applied that generated three basic scenarios ('Do nothing', 'Mitigation', 'Adaptation') and the BAU. Management alternatives along the different phases of the invasion process were identified and described in detail, thus allowing enabling the estimation of monetary impacts that has been described above. A test of consistency of the scenarios unveiled that, while the management strategy tends to favour 'Mitigation' as the scenario that is more consistent with the current policies of water management (at the regional level), 'Adaptation' may be more aligned with the interests of the stakeholders related with recreational activities (at the local level).

Precisely the issue of inter-scale interaction in scenario development is the one addressed in the final section of **Chapter 4**. In this context, the dissertation clarified the conditions under which different interaction methods can be used for local scenario development. Overall, it was recognised that larger forces create framework conditions on a smaller scale that local actors can both benefit from and react to, and local actors in turn respond to these conditions: they resist, cooperate, form alliances, adapt and/or accept bargains. The actual outcome is a result of the dialectic of structural change and the actors' responses, and local scenarios have to take these interactions into account. At this point, attention is drawn to the role of local agency, and in particular, the exploration of agency capabilities of multiple constituencies at the local level. In fact, a formal approach to linking scenario exercises consists of exploring inconsistencies and given the local agency capability, choice of the appropriate interaction strategy, as accommodation or reaction. This innovative proposal is used to understand how three scenarios of bioinvasions in Europe may interact with the four qualitative scenarios for the Ebro River, thus expanding the possibilities for the use of scenario development in management of aquatic bioinvasions.

e. Offering responses

In the same way as the dissertation postulates the benefits of a reflexive model of science, the final chapter of the thesis is devoted to set forth a set of general rules that, based on the findings from previous chapters, aim at increasing the effectiveness of AS management. They are related with the way how to set the objectives of management, the need and ways to improve coordination, the indispensable creation of information hubs, the necessity to tackle bioinvasional meltdowns but confronting first common enemies, the convenience to focus public awareness towards an integrated debate about water quality, the appropriateness of the working scales and encouragement of local agency, the engagement in networking, the use of suitable methods to tackle uncertainty and, finally, the need to set an agenda for management-focused research.

Scope and limitations of the thesis

This thesis innovates in several ways in relation to the socioeconomics of bioinvasions, both empirically and methodologically. Empirically, this is a first exercise to understand the socioeconomics of aquatic bioinvasions in Catalonia, in particular with reference to the implementation of the WFD. This entails, among other applications, a first assessment of the BC&BP indices for fish in the context of the WFD discussions. From the methodological point of view, contributions encompass the method for the estimation of impacts in pre-invasion contexts, the understanding of agency's pivotal role in multi-scale scenario development and the classification of sources of uncertainty in relation with consistent management measures.

Although the research effort has tried to offer a relatively comprehensive view of the issue of managing aquatic bioinvasions, it is clearly lacking in many respects. First – and being totally consistent with the DPSIR framework –, knowledge of specific *pressures* put by aquatic AS has not been explored in depth, although the topic has appeared concisely in **Chapter 2**. This is due to the fact that this type of knowledge is mostly related with biological and ecological characteristics of the species, and therefore has been mostly generated by the biosciences, while the thesis has been centred in the socioeconomics of bioinvasions.

Second, the issue of uncertainty has been addressed along the whole document, and the need to tackle uncertainty with diverse appropriate methods has been included as one of the ten recommendations for AS management. However, the three methods that have been proposed to address uncertainty in the preparation of responses to bioinvasions have not been compared to each other. This is deliberate, as each one of these methods corresponds to different context and aspects of uncertainty, and hence comparing them is not deemed pertinent. Instead, their appropriate use has been suggested (see in **Table 58**).

Reflecting on reflexive science for managing bioinvasions

As stated at the beginning, this thesis is written with the motivation of bringing to potentially interested audiences an outline of the challenges and benefits of a reflexive model of science in the context of managing aquatic bioinvasions. This section presents final considerations on this point, beyond those already introduced in **Chapter 5**, as the final contribution of the dissertation.

Dealing with bioinvasions evidences the lack of a single social perspective on the phenomenon. Both at the Catalan level and in the local case studies addressed, there was a variety of concerns about the alien species and priorities on how to deal with them among the stakeholders under study. Thus, policy-

oriented research on biological invasions faces the need to fit stakeholders' languages and interests into the context in order to gain in scientific quality. Scientific results are bound to be improved through participation: the subject of aquatic invasive species may have been new both for scientists and stakeholders, but the actors' stakes are often higher, and so is their interest in improving the research.

In an engaged research project, results are important but even more important is the process itself. Developing social processes around the knowledge of bioinvasions entails both communication of complexity and the building of trust. Scientists appear as stakeholders at different scales of the bioinvasion issue. They have been able to accompany communication processes that address social responses to bioinvasions. For instance, during workshop or focus groups organised for this research, scientists commonly played as spokespersons of the working groups without leading them but only facilitating the discussion. This procedural result of research is then a powerful line of action for problem-based science. It can be argued that the increased involvement of scientific research can easily lose the neutrality. A conclusion of our research is that this neutrality loss, while transparent, increases the effectiveness of research. While the researcher may be concerned by the loss of scientific independence, his or her work may gain in social relevance and, at the same time, obtain important insights in terms of the nature of the research matter.

Then, accepting the potential benefits of a reflexive model of science for the management of aquatic bioinvasions, which are the major challenges faced?

A reflexive science in relation to AIS management should be aware of the normative and administrative constraints faced. Even in the most prosperous times, let alone the current ones, there might be difficulties for the implementation of top-down traditional policy measures consistent with a linear model of science. In Catalonia, for instance, this is exemplified by the complexities of the normative and administrative framework of the two management areas (biodiversity conservation and water management) that are more involved in tackling aquatic bioinvasions.

Also, the identification of the pertinent use of methods is crucial, trying to promote theoretical and methodological developments that suit best the research queries. In this respect, for instance, research on bioinvasions does not generally use scenario development despite recognised weaknesses in quantitative risk assessment. One should ask: why? A possible explanation is that bioinvasions research has been dominated by the methods of natural science and the approach to the understanding of uncertainty is rather different and very much related with the idea of quantitative or semi-quantitative risk assessment.

On the one hand this calls for caution. Scientific practice should not fall into the temptation of informing the policy cycle with methods that are familiar to the researchers but unappropriated for the type of management requirements. A concrete example in this respect has been the presented in the paradox that entails the calculation of one of the biopollution indices, the BPL. This methodology undoubtedly outshines the other ones introduced in terms of accuracy in portraying the *indicandum*, the state of biopollution. However, in the case of Catalonia it can be argued that the methodology is not useful for management because the amount of resources needed for a proper calculation of BPL is remarkable. Instead of spending resources to recognise how bad the situation is, they could be better used to roughly indicate how bad it might be and to prevent its worsening.

For researchers, this entails the (perhaps) difficult decision to establish research priorities not only according to his/her own preferences. While there is a permanent call from academia to managers to

adopt scientifically-informed decisions, researchers should make a societally-informed choice of research problems. After that, the decision is of the researcher only.

On the other hand, there should be acceptance of the delicate balance between rigueur, timing and available resources. This balance may lead to counter-intuitive recommendations – like 'let's promote more scientifically robust, evidence-based management measures' – when encouraging democratisation of expertise. Scientists working in a normal (positive, linear) model of science have been the ones making most of the contributions so far in relation to aquatic bioinvasions. While plurality of perspectives and valuation languages is clearly needed, the conditions for opening a debate that accompanies integrated management may not exist for a variety of reasons (e.g., because more urgent, more relevant, more uncertain topics than aquatic bioinvasions dominate the societal debates). When the post-normal scientist observes (from the comfort of his desk) mismatches between the needs of management and the outcomes of scientific endeavours, there might be a lack of awareness of these practical difficulties.

In this context, 'normal' researchers – because of their consistent interest in promoting a management agenda for aquatic environments, even in times of economic crises, and because of the stock of accumulated knowledge of the issue over the years – may become major stakeholders whose view needs to be explicitly included in the management agenda. Then, it is only logical to expect that a prescription for more positive science will be in the 'reflexive research agenda' (e.g., 'more information about impacts of the species needed'). While the science-management feedback remains, so do the management measures. There are more chances for further societal engagement with policies against bioinvasions if these policies actually exist.

Of course, this is not the only reason to defend normal science in the context of biological invasions. There are many aspects of the invasions, outlined above, that critically require scientific attention. Again, from everything the author has learned in her own research experience, the highlight is that scientific activities, in their interaction with concrete management processes, are likely to find increased and more relevant opportunities for development.

References

Acuanor, 2007. El Ministerio de Medio Ambiente instala en Cantabria la estación de filtrado más grande de España para prevenir la aparición de mejillón cebra en el Norte [The Ministry of the Environment installs the largest filtering plant in Spain for preventing the ar [WWW Document].

Adams, K.M., 2012. Ethnographic methods, in: Dwyer, L., Gill, A., Seetaram, N. (Eds.), Handbook of Research Methods in Tourism. Quantitative and Qualitative Approaches. Edward Elgar, pp. 339–351.

Agència Catalana de l'Aigua (ACA), 2004. Estudi tècnic justificatiu de l'ordenació dels usos recreatius dels embassaments de Boadella, Susqueda i Pasteral (Zona Nord). Susqueda i Pasteral [WWW Document]. URL http://aca-web.gencat.cat/aca/documents/ca/planificacio/usos_recreatius/embassament_susqueda_el_pasteral.pdf (accessed 4.16.14).

Agència Catalana de l'Aigua (ACA), 2005. Estudi tècnic justificatiu de l'ordenació dels usos recreatius a l'embassament de Sau [WWW Document]. URL http://aca-web.gencat.cat/aca/documents/ca/planificacio/usos_recreatius/embassament_sau.pdf (accessed 4.16.14).

Agència Catalana de l'Aigua (ACA), 2006a. BIORI. Protocol d'avaluació de la qualitat biològica dels rius. Departament de Medi Ambient i Habitatge, Generalitat de Catalunya, Barcelona.

Agència Catalana de l'Aigua (ACA), 2006b. ECOZO. Protocol d'avaluació de l'estat ecològic de les zones humides. Departament de Medi Ambient i Habitatge, Generalitat de Catalunya, Barcelona.

Agència Catalana de l'Aigua (ACA), 2006c. ECOEM. Protocol d'avaluació del potencial ecològic dels embassaments. Departament de Medi Ambient i Habitatge, Generalitat de Catalunya, Barcelona.

Agència Catalana de l'Aigua (ACA), 2006d. HIDRI. Protocol per a la valoració de la qualitat hidromorfològica dels rius. Departament de Medi Ambient i Habitatge, Generalitat de Catalunya, Barcelona.

Agència Catalana de l'Aigua (ACA), 2006e. ECOES. Protocol d'avaluació de l'estat ecològic dels estanys. Departament de Medi Ambient i Habitatge, Generalitat de Catalunya, Barcelona.

Agència Catalana de l'Aigua (ACA), 2007a. Proposta de les normes de navegació a piragüisme en trams fluvials de les Conques Internes de Catalunya [WWW Document]. URL http://aca-web.gencat.cat/aca/documents/ca/planificacio/usos_recreatius/normes_de_navegacio_a_piraguisme_cic.pdf

Agència Catalana de l'Aigua (ACA), 2007b. L'estat de la invasió de musclo zebra (*Dreissena polymorpha*) a Catalunya. Flix.

Agència Catalana de l'Aigua (ACA), 2008. Water in Catalonia. Diagnosis and proposed actions: significant water management issues raised within the compilation of the River Basin District Management Plan for Catalonia. Departament de Medi Ambient i Habitatge, Barcelona.

Agència Catalana de l'Aigua (ACA), 2009a. Estratègia de prevenció a la possible invasió del musclo zebrat (*Dreissena polymorpha*) a les masses d'aigua de Catalunya. Definició dels escenaris d'alerta i pre-alerta i procediments davant d'un avís de detecció [WWW Document]. URL http://aca-web.gencat.cat/aca/documents/ca/aigua_medi/especies_invasores/memoria_protocols.pdf (accessed 4.15.14).

Agència Catalana de l'Aigua (ACA), 2009b. Nous criteris tècnics respecte a la navegació [WWW Document]. URL http://aca-web.gencat.cat/aca/documents/ca/sollicituds/criteris_navegacio.pdf (accessed 4.16.14).

Agència Catalana de l'Aigua (ACA), 2010a. Informe de sostenibilitat ambiental del Programa de mesures del Pla de gestió del districte de conca fluvial de Catalunya. BLOC 1: Millora de la qualitat hidromorfològica i biològica [WWW Document]. URL http://aca-web.gencat.cat/aca/documents/ca/legislacio/projectes/PdM/ISA_Bloc_1.pdf (accessed 4.13.14).

Agència Catalana de l'Aigua (ACA), 2010b. 5. Descripció de les mesures adoptades per a la millora de la qualitat hidromorfològica i biològica del medi [WWW Document]. Programa Mes. del Pla gestió del Dist. conca Fluv. Catalunya. URL http://aca-web.gencat.cat/aca/documents/ca/legislacio/projectes/PdM/CAPITOL_05.pdf (accessed 4.13.14).

Agència Catalana de l'Aigua (ACA), 2010c. Estratègia de prevenció a la possible invasió del musclo zebrat (*Dreissena polymorpha*) a les masses d'aigua de Catalunya. Índex de Susceptibilitat MZCat. Barcelona.

Agència Catalana de l'Aigua (ACA), 2011. Processos participatius i Directiva Marc de l'Aigua [WWW Document]. URL http://aca-web.gencat.cat/aca/documents/ca/participacio/portal/index.pdf (accessed 12.31.13).

Agència Catalana de l'Aigua (ACA), 2012. Musco zebat. Material de divulgació. Actualització 29 de setembre de 2012 [WWW Document]. URL http://aca-

web.gencat.cat/aca/documents/ca/aigua_medi/especies_invasores/Material_Divulgacio_Zebrat.pdf (accessed 4.15.14).
Agència Catalana de l'Aigua (ACA), 2014a. Característiques tècniques i capacitat embassaments de Catalunya. Conques intercomunitàries.
Agència Catalana de l'Aigua (ACA), 2014b. El musclo zebrat. Estat de la presència a Catalunya - 2013. Barcelona.
Agència Catalana de l'Aigua (ACA), 2014c. Musclo zebrat. Documents tècnics. Actualització 26 de febrer de 2014 [WWW Document]. URL http://aca-web.gencat.cat/aca/documents/ca/aigua_medi/especies_invasores/Documents_Tecnics_Zebrat.pdf (accessed 4.15.14).
Agència Catalana de l'Aigua (ACA), 2014d. Declaració responsable de navegació i flotació: Instruccions i requisits [WWW Document]. URL http://aca-web.gencat.cat/aca/documents/ca/sollicituds/ACA_instruccions_requisits_declaracio_responsable_navegacio_ca.pdf (accessed 4.16.14).
Agricultural Geo-Referenced Information System (AGIS), 2007. Weeds & invasive plant of South Africa. accessed from www.agis.agric.za 23/10/2012.
Agua de las Cuencas Mediterráneas (AcuaMed), 2012. FCC adjudicataria de la descontaminación del embalse de Flix 24/04/2012 [WWW Document]. Descontaminación Flix. URL http://decontaminationflix.com/index.php?p=noticia&c=8 (accessed 4.13.14).
Aigües del Ter Llobregat (ATLL), 2004. Planta potabilitzadora del Ter.
Aigües del Ter Llobregat (ATLL), 2012. Memòria d'activitats i responsabilitat corporativa d'Aigües del Ter Llobregat. Any 2011. Departament de Territori i Sostenibilitat, Barcelona.
Albins, M.A., Hixon, M.A., 2013. Worst case scenario: Potential long-term effects of invasive predatory lionfish (Pterois volitans) on Atlantic and Caribbean coral-reef communities. Environ. Biol. Fishes 96, 1151–1157.
Alfasi, N., Fenster, T., 2009. Between the "Global" and the "Local": On Global Locality and Local Globality. Urban Geogr. doi:10.2747/0272-3638.30.5.543
Alowe, S., Browne, M., Boudjelas, S., De Poorter, M., 2000. 100 of the world's worst invasive alien species: a selection from the global invasive species database, 100 of the world's worst invasive alien species: a selection from the global invasive species database. Auckland,, New Zealand: Invasive Species Specialist Group.
Ambiens. Gestió de Recursos Ambientals, 2014. Projectes destacats. Llei d'ordenació sostenible de la pesca [WWW Document]. URL http://www.ambiens.cat/cms/ca/biodiversitat/projectes_destacats/llei_pesca.html (accessed 4.4.12).
Anastasi, C., 2003. On the art of scenario development, in: Kasemir, B. (Ed.), Public Participation in Sustainability Science: A Handbook. Cambridge University Press,, Cambridge, pp. 201–212.
Andersen, M.C., Adams, H., Hope, B., Powell, M., 2004. Risk assessment for invasive species. Risk Anal. 24, 787–793.
Anderson, L.W.J., 2005. California's reaction to *Caulerpa taxifolia*: a model for invasive species rapid response. Biol. Invasions. doi:10.1007/s10530-004-3123-z
Andow, D.A., 2003. Biological invasions: assessment and management of environmental risk, in: Proceedings of International Seminar on Biological Invasions. NIAES and FFTC. pp. 1–29.
Andreu, J., Pino, J., Basnou, C., Guardiola, M., Ordóñez, J.L., 2012. Les espècies exòtiques de Catalunya. Resum del projecte EXOCAT 2012. Generalitat de Catalunya. Departament d'Agricultura, Ramaderia, Pesca, Alimentació i Medi Natural, Barcelona.
Andreu, J., Pino, J., Rodríguez-Labajos, B., Munné, A., 2011. Avaluació de l'estat i el risc d'invasió per espècies exòtiques dels ecosistemes aquàtics de Catalunya. Agència Catalana de l'Aigua, Departament de Medi Ambient i Habitatge, Generalitat de Catalunya.
Angrosino, M., 2007. Doing Ethnographic and Observational Research, The SAGE Qualitative Research Kit.
Anil, A.C., Clarke, C., Hayes, T., Hilliard, R., Joshi, G., Krishnamurthy, V., Polglaze, J., S.S., S., Raaymakers, S., 2004. Ballast Water Risk Assessment, Ports of Mumbai and Jawaharlal Nehru, India, October 2003: Final Report. London.
Arbačiauskas, K., Semenchenko, V., Grabowski, M., Leuven, R., Paunović, M., Son, M.O., Csányi, B., Gumuliauskaitė, S., Konopacka, A., Nehring, S., 2008. Assessment of biocontamination of benthic macroinvertebrate communities in European inland waterways. Aquat. Invasions 3, 211–230.
Arlinghaus, R., 2007. Voluntary catch-and-release can generate conflict within the recreational angling community: a qualitative case study of specialised carp, Cyprinus carpio</i>, angling in Germany. Fish. Manag. Ecol. 14, 161–171. doi:10.1111/j.1365-2400.2007.00537.x

Armengol, J., Navarro, E., 2003. Caracterització i propostes d'estudi dels embassaments catalans segons la Directiva 2000/60/CE del Parlament Europeu. Agència Catalana de l'Aigua, Departament de Medi Ambient i Habitatge, Generalitat de Catalunya, Barcelona.

Asociación Nuclear Ascó –Vandellós, 2003. Actuaciones preventivas en la Central Nuclear de Ascó frente a una posible invasión del mejillón cebra [Preventive actions in the Ascó nuclear power plant against the possible invasion of the zebra mussel]. Asociación Nuclear Ascó -Vandellós - Medi Ambient, Zaragoza.

Aukema, J.E., Leung, B., Kovacs, K., Chivers, C., Britton, K.O., Englin, J., Frankel, S.J., Haight, R.G., Holmes, T.P., Liebhold, A.M., 2011. Economic impacts of non-native forest insects in the continental United States. PLoS One 6, e24587.

Aven, T., Steen, R., 2010. The concept of ignorance in a risk assessment and risk management context. Reliab. Eng. Syst. Saf. doi:10.1016/j.ress.2010.05.006

Awad, A., Clarke, C., Greyling, L., Hilliard, R., Polglaze, J., Raaymakers, S., 2004. Ballast Water Risk Assessment. Port of Saldanha Bay, Republic of South Africa. London.

Baker, R.H.A., Black, R., Copp, G.H., Haysom, K.A., Hulme, P.E., Thomas, M.B., Brown, A., Brown, M., Cannon, R.J.C., Ellis, J., Ellis, M., Ferris, R., Glaves, P., Gozlan, R.E., Holt, J., Howe, L., Knight, J.D., MacLeod, A., Moore, N.P., Mumford, J.D., Murphy, S.T., Parrott, D., Sansford, C.E., Smith, G.C., St-Hilaire, S., Ward, N.L., 2008. The UK risk assessment scheme for all non-native species, in: Rabitsch, W., Essl, F., Klingenstein, F. (Eds.), Biological Invasions – from Ecology to Conservation. NEOBIOTA 7. pp. 46–47.

Ballesteros, E., Garcia, M., Torras, X., Weitzmann, B., Fragela, M.M., Pinedo, S., Jordana, E., Satta, M.P., 2010. Informe del Programa de vigilància de la qualitat de les aigües litorals de Catalunya en funció de les comunitats de macroalgues, segons la Directiva Marc de l'Aigua i de la prevenció de la implantació d'espècies invasores. Informe final 2010. Blanes.

Ballesteros, E., Pinedo, S., Garcia, M., Torras, X., Jordana, E., Satta, M.P., Weitzmann, B., Lopez, P., Arévalo, R., 2004. Informe del programa: Estudi de la vunerabilitat i de la qualitat ambiental dels fons marins i de la zona litoral a Catalunya i Prevenció de la implantació de Caulerpa taxifolia. Informe final 2004.

Ballesteros, E., Pinedo, S., Garcia, M., Torras, X., Jordana, E., Satta, M.P., Weitzmann, B., Lopez, P., Arévalo, R., 2005. Informe del programa: Estudi de la vunerabilitat i de la qualitat ambiental dels fons marins i de la zona litoral a Catalunya i Prevenció de la implantació de Caulerpa taxifolia. Informe final 2005.

Balsells, F., 2009. Cataluña permite la exportación a Rumania de un pez tóxico del Ebro. El País.

Bandura, A., 1989. Human agency in social cognitive theory. Am. Psychol. 44, 1175–1184.

Bandura, A., 2000. Exercise of human agency through collective efficacy. Curr. Dir. Psychol. Sci. 9, 75.

Bandura, A., 2002. Social cognitive theory in cultural context. Appl. Psychol. An Int. Rev. 51, 269–290. doi:10.1111/1464-0597.00092

Barbier, E.B., 2001. A note on the economics of biological invasions. Ecol. Econ. 39, 197–202.

Barton, D.R., Kelton, N., Eedy, R.I., 2000. The effects of carp (*Cyprinus carpio* L.) on sediment export from a small urban impoundment. J. Aquat. Ecosyst. Stress Recover. (Formerly J. Aquat. Ecosyst. Heal. 8, 155–159.

Bax, N., Williamson, A., Aguero, M., Gonzalez, E., Geeves, W., 2003. Marine invasive alien species: a threat to global biodiversity. Mar. Policy 27, 313–323.

Beck, S., 2011. Moving beyond the linear model of expertise? IPCC and the test of adaptation. Reg. Environ. Chang. 11, 297–306.

Benejam, L., Benito, J., García-Berthou, E., 2010. Decreases in condition and fecundity of freshwater fishes in a highly polluted reservoir. Water, Air, Soil Pollut. doi:10.1007/s11270-009-0245-z

Benejam, L., Carol, J., Benito, J., García-Berthou, E., 2007. On the spread of the European catfish (*Silurus glanis*) in the Iberian Peninsula: first record in the Llobregat river basin. Limnetica 26, 169–171.

Berkhout, F., Hertin, J., 2003. Foresight futures scenarios: developing and applying a participative strategic planning tool. Greener Manag. Int. 37, 37–52.

Bertrand, G., Michalski, A., Pench, L.R., 1999. Scenarios Europe 2010. Five possible futures for Europe. European Commission Forward Studies Unit.

Biggs, R., Raudsepp-hearne, C., Atkinson-palombo, C., Bohensky, E., Boyd, E., Cundill, G., Fox, H., Ingram, S., Kok, K., Spehar, S., Tengö, M., 2007. Linking Futures across Scales : a Dialog on Multiscale Scenarios. Ecol. Soc. 12, Online. doi:10.1016/s0742-3322(06)23017-1

Binimelis, R., Born, W., Monterroso, I., Rodríguez-Labajos, B., 2007a. Socio-economic impact and assessment of biological invasions. Ecol. Stud. 193 (Biolo, 331–347.

Binimelis, R., Monterroso, I., Rodriguez-Labajos, B., 2007b. A social analysis of the bioinvasions of *Dreissena polymorpha* in Spain and *Hydrilla verticillata* in Guatemala. Environ. Manage. 40, 555–566.

Binimelis, R., Monterroso, I., Rodríguez-Labajos, B., 2009a. Catalan agriculture and genetically modified organisms (GMOs)—An application of DPSIR model. Ecol. Econ. 69, 55–62.
Binimelis, R., Pengue, W., Monterroso, I., 2009b. "Transgenic treadmill": Responses to the emergence and spread of glyphosate-resistant johnsongrass in Argentina. Geoforum 40, 623–633.
Binimelis, R., Rodriguez-Labajos, B., 2007. Socio-economic assessment of risks of invasive species to freshwater ecosystem goods and services on a basin scale, in: Proceedings of the Conference Risk Assessment in European River Basins - State of the Art and Future Challenges. Leipzig, pp. 63–66.
Biosca, J., 2014. Cargol poma: Reunió entre Ministeri, DAAM i JARC-COAG. Mon Rural 120, 14.
Blackburn, T.M., Pyšek, P., Bacher, S., Carlton, J.T., Duncan, R.P., Jarošík, V., Wilson, J.R.U., Richardson8, D.M., 2011. A proposed unified framework for biological invasions. Trends Ecol. Evol. 26, 333–339.
Blanc, G., 1997. Introduction of pathogens in European aquatic ecosystems: Attempt of evaluation and realities. Bull. Français la Pêche la Piscic. 344-345, 489–513.
Bohunovsky, L., Jäger, J., Omann, I., 2010. Participatory scenario development for integrated sustainability assessment. Reg. Environ. Chang. 11, 271–284. doi:10.1007/s10113-010-0143-3
Boletín Oficial del Estado (BOE), 2001a. Real Decreto Legislativo 1/2001, de 20 de julio, por el que se aprueba el texto refundido de la Ley de Aguas.
Boletín Oficial del Estado (BOE), 2001b. Ley 10/2001, de 5 de julio, del Plan Hidrológico Nacional.
Boletín Oficial del Estado (BOE), 2003. Ley 62/2003, de 30 de Diciembre, de medidas fiscales, administrativas y de orden social.
Boletín Oficial del Estado (BOE), 2004. Real Decreto-ley 2/2004, de 18 de junio, por el que se modifica la Ley 10/2001, de 5 de julio, del Plan Hidrológico Nacional.
Boletín Oficial del Estado (BOE), 2006. Ley Orgánica 6/2006, de 19 de julio, de reforma del Estatuto de Autonomía de Cataluña.
Boletín Oficial del Estado (BOE), 2007. Ley 42/2007, de 13 de diciembre, del Patrimonio Natural y de la Biodiversidad.
Boletín Oficial del Estado (BOE), 2010. Pleno. Sentencia 31/2010, de 28 de junio de 2010. Recurso de inconstitucionalidad 8045-2006. Interpuesto por noventa y nueve Diputados del Grupo Parlamentario Popular del Congreso en relación con diversos preceptos de la Ley Orgánica 6/2006, de 19 de juli.
Boletín Oficial del Estado (BOE), 2011a. Real Decreto 1628/2011, de 14 de noviembre, por el que se regula el listado y catálogo español de especies exóticas invasoras.
Boletín Oficial del Estado (BOE), 2011b. Real Decreto 139/2011, de 4 de febrero, para el desarrollo del Listado de Especies Silvestres en Régimen de Protección Especial y del Catálogo Español de Especies Amenazadas.
Boletín Oficial del Estado (BOE), 2012a. Auto de 28 de marzo de 2012, de la Sala Tercera del Tribunal Supremo, por el que se decreta la suspensión de la vigencia del Real Decreto 1628/2011, de 14 de noviembre, por el que se regula el listado y catálogo español de especies exóticas invasoras.
Boletín Oficial del Estado (BOE), 2012b. Resolución de 13 de marzo de 2012, de la Dirección General de Calidad y Evaluación Ambiental y Medio Natural, por la que se publica el Acuerdo de Consejo de Ministros de 24 de febrero de 2012, por el que se da contestación a los requerimientos planteados.
Boletín Oficial del Estado (BOE), 2013. Real Decreto 630/2013, de 2 de agosto, por el que se regula el Catálogo español de especies exóticas invasoras.
Booy, O., White, V., Wade, M., 2006. Non-native organism Risk Assessment Scheme: trialling and peer review (Scottish Executive reference: FF/05/22). Edinburgh.
Boquera Margalef, M., Quiroga Raimundez, V., 2001. De la saboga al silur. Perscadors fluvials de l'Ebre a Tivenys, 2001. Generalitat de Catalunya - Centre de Promocio de la Cultura Popular i Tradicional Catalana, Barcelona.
Borer, D.A., 2005. Opposing Suharto: Compromise, Resistance, and Regime Change in Indonesia. Hist. Rev. New Books. doi:10.1080/03612759.2005.10526753
Born, W., 2008. Ecological-economic assessment of biological invasions. A conceptual contribution on the basis of the concept of ecosystem services. PhD Thesis, Helmholtz-Zentrum für Umweltforschung - UFZ / Martin-Luther-Universität Halle-Wittenberg, Leipzig.
Born, W., Rauschmayer, F., Brauer, I., 2005. Economic evaluation of biological invasions--a survey. Ecol. Econ. 55, 321–336.
Bosch i Suades, C., 2009. Contaminació per compostos orgànics persistents en el sistema fluvial de l'Ebre. Universitat de Barcelona.
Boudouresque, C.F., Verlaque, M., 2002. Biological pollution in the Mediterranean Sea: invasive versus introduced macrophytes. Mar. Pollut. Bull. 44, 32–38.

Boyer, E.L., 1996. The Scholarship of Engagement. Bull. Am. Acad. Arts Sci. 49, 18–33.
Braig, E.C., Johnson, D.L., 2003. Impact of black bullhead (*Ameiurus melas*) on turbidity in a diked wetland. Hydrobiologia 490, 11–21.
Bright, C., 1999. Invasive species: pathogens of globalization. Foreign Policy 116, 50–64.
Brousseau, E., Dedeurwaerdere, T., Siebenhüner, B., 2012. Reflexive governance for global public goods. MIT Press, Cambridge, MA and London.
Brown, J.C., Purcell, M., 2005. There's nothing inherent about scale: Political ecology, the local trap, and the politics of development in the Brazilian Amazon. Geoforum.
Buckley, Y.M., 2008. The role of research for integrated management of invasive species, invaded landscapes and communities. J. Appl. Ecol.
Burawoy, M., 2009. The extended case method: Four countries, four Decades, four great transformations and one theoretical tradition. University of California Press, Berkeley.
Butlletí Oficial del Parlament de Catalunya (BOPC), 2008. Projecte de llei d'ordenació sostenible de la pesca continental (13/11/08).
Byrne, J., Hughes, K., Rickerson, W., Kurdgelashvili, L., 2007. American policy conflict in the greenhouse: Divergent trends in federal, regional, state, and local green energy and climate change policy. Energy Policy 35, 4555–4573.
Caffrey, J.M., Baars, J., Barbour, J.H., Boets, P., Boon, P., Davenport, K., Dick, J.T.A., Early, J., Edsman, L., Gallagher, C., Gross, J., Heinimaa, P., Horrill, C., Hudin, S., Hulme, P.E., Hynes, S., Macisaac, H.J., 2014. Tackling Invasive Alien Species in Europe : the top 20 issues. Manag. Biol. Invasions 5, 1–20.
Caille, F., Riera, J.L., Rodríguez-Labajos, B., Middelkoop, H., Rosell-Melé, A., 2007. Participatory scenario development for integrated assessment of nutrient flows in a Catalan river catchment. Hydrol. Earth Syst. Sci. Discuss. doi:10.5194/hessd-4-1265-2007
Cambray, J.A., 2003. Impact on indigenous species biodiversity caused by the globalisation of alien recreational freshwater fisheries. Hydrobiologia.
Campbell, F., Kriesch, P., 2003. Invasive species pathways Team. Final Report, NISC - USDA/APHIS.
Campbell, M.L., 2013. The pointy end of the stick: managing biological invasions. Manag. Biol. Invasions 4, 1–2.
Canal Parlament, 2009a. Compareixença de Carles Pla i Zanuy, representant del Consell Interuniversitari de Catalunya, amb relació al Projecte de llei d'ordenació sostenible de la pesca continental (Exp: 353-00533/08). Comissió de Medi Ambient i Habitatge. 07/05/2009 - sessió ord [WWW Document]. URL http://www.parlament.cat/web/actualitat/canal-parlament/sequencia/videos?p_cp1=372736&p_cp3=372918
Canal Parlament, 2009b. Compareixença d'Adolf de Sostoa Fernández, de la Facultat de Biologia de la Universitat de Barcelona, amb relació al Projecte de llei d'ordenació sostenible de la pesca continental (Exp: 353-00535/08). Comissió de Medi Ambient i Habitatge. 07/05/2009 [WWW Document]. URL http://www.parlament.cat/web/actualitat/canal-parlament/sequencia/videos?p_cp1=372736&p_cp3=373052 (accessed 4.9.14).
Cardoso, A.C., Free, G., 2008. Incorporating invasive alien species into ecological assessment in the context of the Water Framework Directive. Aquat. Invasions 3, 361–366.
Carlton, J.T., 1996. Pattern, process, and prediction in marine invasion ecology. Biol. Conserv. 78, 97–106.
Carlton, J.T., 2003. Community assembly and historical biogeography in the North Atlantic Ocean: the potential role of human-mediated dispersal vectors. Hydrobiologia 503, 1–8.
Carol Bruguera, J., 2007. Ecology of an invasive fish (*Silurus glanis*) in Catalan reservoirs. PhD Thesis, Universitat de Girona, Girona.
Carol, J., Benejam, L., Benito, J., García-Berthou, E., 2009. Growth and diet of European catfish (*Silurus glanis*) in early and late invasion stages. Fundam. Appl. Limnol. / Arch. für Hydrobiol. 174, 317–328.
Carol, J., García-Berthou, E., 2010. Siluro – <i>Silurus glanis, in: Salvador, A., Elvira, B. (Eds.), Enciclopedia Virtual de Los Vertebrados Españoles. Museo Nacional de Ciencias Naturales, Madrid.
Carpenter, S.R., Bennett, E.M., Peterson, G.D., 2006. Scenarios for ecosystem services: an overview. Ecol. Soc. 11, 29.
Carr, G.M., Neary, J.P., 2008. Water quality for ecosystem and human health. Burlington: United Nations Environment Programme, Global Environment Monitoring System, Ontario.
Carrasco, L., Barata, C., García-Berthou, E., Tobias, A., Bayona, J.M., Díez, S., 2011. Patterns of mercury and methylmercury bioaccumulation in fish species downstream of a long-term mercury-contaminated site in the lower Ebro River (NE Spain). Chemosphere 84, 1642–1649.
Case, T.J., 1996. Global patterns in the establishment and distribution of exotic birds. Biol. Conserv. 78, 69–96.

Cassey, P., Blackburn, T.M., Russell, G.J., Jones, K.E., Lockwood, J.L., 2004. Influences on the transport and establishment of exotic bird species: an analysis of the parrots (Psittaciformes) of the world. Glob. Chang. Biol. 10, 417–426.
Centre d'Estudis de la Batalla de l'Ebre (CEBE), 2014. La Batalla [WWW Document]. Cent. d'Estudis la Batalla l'Ebre. URL http://www.fut.es/~cebe/ (accessed 4.14.14).
Chapman, R.A., Le Maitre, D.C., Richardson, D.M., 2001. Scenario planning: understanding and managing biological invasions in South Africa, in: McNeely, J.A. (Ed.), The Great Reshuffling: Human Dimensions of Invasive Alien Species. IUCN, Gland, Switzerland and Cambridge, UK, pp. 195–208.
Charles, H., Dukes, J.S., 2007. Impacts of invasive species on ecosystem services, in: Nentwig, W. (Ed.), Biological Invasions (Ecological Studies, 193). Springer, Berlin, pp. 217–237. doi:10.1007/978-3-540-36920-2_13
Chu, D., Strand, R., Fjelland, R., 2003. Theories of complexity. Complexity 8, 19–30.
Cia-Abaurre, I., 2011. Invasibilitat i potencial invasor en invertebrats. Anàlisis del risc d'invasió del musclo zebrat a Catalunya, in: L'anàlisi Del Risc de Les Invasions Biològiques En Ecosistemes Aquàtics: Revisió Metodològica I Propostes de Gestió. CREAF-ACA, Bellaterra, p. 55.
Clarke, C., Hilliard, R., Liuy, Y., Polglaze, J., Zhao, D., Xu, X., Raaymakers, S., 2004. Ballast Water Risk Assessment, Port of Dalian, People's Republic of China, November 2003: Final Report. Kondon.
Clavero, M., García-Berthou, E., 2005. Invasive species are a leading cause of animal extinctions. Trends Ecol. Evol.
Clout, M.N., Williams, P.A., 2009. Invasive species management: a handbook of principles and technicalities. Oxford University Press, New York.
Colautti, R.I., MacIsaac, H.I., 2004. A neutral terminology to define "invasive" species. Divers. Distrib. 10, 135–141.
Colomy, P., 1998. Neofunctionalism and Neoinstitutionalism: Human Agency and Interest in Institutional Change. Sociol. Forum 13, 265–300.
Comisión Nacional de Energía (CNE), 2000. Anexo V. Centrales Eléctricas Pertenencientes a Iberdrola y Endesa. Informe sobre el proyecto de concentración consistente en la fusión de ENDESA, S.A. e IBERDROL S.A.
Comité Científico de SEO/BirdLife, 2012. Manifiesto. Importancia de la lucha contra las especies exóticas invasoras [WWW Document]. URL http://www.seo.org/wp-content/uploads/2012/05/Manifiesto_RD_Invasoras_CC_SEO_OK.pdf (accessed 4.3.14).
Confederación Hidrográfica del Cantábrico (CHC), 2011. Resultados de los trabajos de seguimiento del mejillón cebra en la cuenca del Arratia (Al 20-07-2011) [WWW Document]. URL http://www.chcantabrico.es/images/pdf/actuaciones/gestion_dph/conservacion_restauracion/conservacion_cauces/informe_situacion_mejilloncebra_arratia_20110720.pdf (accessed 4.14.14).
Confederación Hidrográfica del Ebro (CHE), 2008. Sistema Automático de Información Hidrológica de la Cuenca del Ebro (SAIH) [WWW Document]. URL http://195.55.247.237/saihebro/ (accessed 12.1.08).
Conference of the Parties of the Convention on Biological Diversity (CBD), 1992. Convention on Biological Diversity. Text of the Convention [WWW Document].
Conference of the Parties of the Convention on Biological Diversity (CBD), 2002. COP 6 Decision VI/23. Alien species that threaten ecosystems, habitats or species, Annex: Guiding principles for the prevention, introduction and mitigation of impacts of alien species that threaten ecosystems, habitats or species. The Hague, 7 - 19 April [WWW Document].
Conferencia Sectorial de Medio Ambiente (CSMA), 2007. Estrategia Nacional para el Control del Mejillón Cebra. Madrid.
Conrad, M., 1979. Ecosystem stability and bifurcation in the light of adaptability theory, in: Gurel, O., Rössler, O. (Eds.), Bifurcation Theory and Its Applications in Scientific Disciplines. New York Academy of Sciences, New York, pp. 465–482.
Conroy, J.D., Edwards, W.J., Pontius, R.A., Kane, D.D., Zhang, H., Shea, J.F., Richey, J.N., Culver, D.A., 2005. Soluble nitrogen and phosphorus excretion of exotic freshwater mussels (*Dreissena* spp.): potential impacts for nutrient remineralisation in western Lake Erie. Freshw. Biol. 50, 1146–1162. doi:10.1111/j.1365-2427.2005.01392.x
Copp, G.H., Garthwaite, R., Gozlan, R.E., 2005. Risk identification and assessment of non-native freshwater fishes: a summary of concepts and perspectives on protocols for the UK. J. Appl. Ichthyol. 21, 371–373.
Copp, G.H., Moffatt, L., Wesley, K.J., 2007. Is European catfish *Silurus glanis* really becoming more abundant in the River Thames? Aquat. Invasions 2, 113–116. doi:http://dx.doi.org/10.3391/ai.2007.2.2.5

Copp, G.H., Vilizzi, L., Mumford, J., Fenwick, G. V, Godard, M.J., Gozlan, R.E., 2009. Calibration of FISK, an invasiveness screening tool for nonnative freshwater fishes. Risk Anal. 29, 457–467.
Cortey, M., Pla, C., García-Marín, J.L., 2004. Historical biogeography of Mediterranean trout. Mol. Phylogenet. Evol. 33, 831–844.
Cotín, J., García-Tarrasón, M., Jover, L., Sanpera, C., 2012. Are the toxic sediments deposited at Flix reservoir affecting the Ebro river biota? Purple heron eggs and nestlings as indicators. Ecotoxicology. doi:10.1007/s10646-012-0893-4
Crivelli, A.J., 1995. Are fish introductions a threat to endemic freshwater fishes in the northern Mediterranean region? Biol. Conserv. doi:10.1016/0006-3207(94)00092-5
Crosby, A.W., 1972. The Columbian exchange: biological and cultural consequences of 1492. Greenwood Publishing Group, Westport, Conn.
Crow, M.M., 2011. Time to rethink the NIH. Nature 471, 569–571.
Daily, G.C., 1997. Nature's services: societal dependence on natural ecosystems. Island Press, Washinton D.C. and Covelo, California.
Dalmazzone, S., 2000. Economic factors affecting vulnerability to biological invasions, in: Perrings, C. (Ed.), The Economics of Biological Invasions. Edward Elgar Publishing, Cheltenham, UK, pp. 17–30.
Dark, S.J., 2004. The biogeography of invasive alien plants in California: an application of GIS and spatial regression analysis. Divers. Distrib. 10, 1–9.
Dehnen-Schmutz, K., 2004. Alien species reflecting history: medieval castles in Germany. Divers. Distrib. 10, 147–151.
Delisle, F., Lavoie, C., Jean, M., Lachance, D., 2003. Reconstructing the spread of invasive plants: taking into account biases associated with herbarium specimens. J. Biogeogr. 30, 1033–1042.
Departament d'Agricultura Ramadaria Pesca Alimentacio i Medi Natural (DAAM), 2012. Informe cargol poma. Juny 2012 [WWW Document]. URL http://premsa.gencat.cat/pres_fsvp/docs/2012/06/25/12/27/b57b22cb-2701-4140-a082-02fe2e8fcb86.ppt#256,1,INFORME CARGOL POMA (accessed 4.11.14).
Departament d'Agricultura Ramadaria Pesca Alimentacio i Medi Natural (DAAM), 2013. Pla d'acció contra el cargol poma (Pomacea insularum) al Delta de l'Ebre 2013 [WWW Document]. URL http://www20.gencat.cat/docs/DAR/AG_Agricultura/AG02_Sanitat_vegetal/AG02_02_Plagues/Documents/Fitxers_estatics/Cargol_poma_pla_accio.pdf (accessed 4.11.14).
Departament d'Agricultura Ramaderia Pesca Alimentació i Medi Natural d'Agricultura (DAAM), 2014. Pla de lluita Cargol Poma. Resultats 2013.
Department of Environmental Affairs and Tourism (DEAT), 1999. National State of the Environment Report - South Africa [WWW Document].
Department of Environmental Affairs and Tourism (DEAT), 2006. National State of the Environment Report - South Africa, 2006 [WWW Document].
Desmarais, A.A., 2007. La Vía Campesina: globalization and the power of peasants. Fernwood Pub., Halifax.
Diari Oficial de la Generalitat de Catalunya (DOGC), 2009. Llei 22/2009, de 23 de desembre, d'ordenació sostenible de la pesca a aigües continentals.
Diari Oficial de la Generalitat de Catalunya (DOGC), 2010a. Acord GOV/238/2010, de 23 de novembre, pel qual s'aprova el Programa de Mesures del Pla de Gestió del Districte de Conca Fluvial de Catalunya.
Diari Oficial de la Generalitat de Catalunya (DOGC), 2010b. Decret 188/2010, de 23 de novembre, d'aprovació del Pla de gestió del districte de conca fluvial de Catalunya.
Diari Oficial de la Generalitat de Catalunya (DOGC), 2011. Ley 9/2011, de 29 de diciembre, de promoción de la actividad económica.
Diari Oficial de la Generalitat de Catalunya (DOGC), 2012. Resolució TES/1850/2012, d'1 d'agost, per la qual s'estableix la classiicació dels embassa- ments, estanys i trams dels rius de les conques internes de Catalunya a efectes de la navegació i el bany.
Diari Oficial de la Generalitat de Catalunya (DOGC), 2013a. Resolución AAM/506/2013, de 7 de marzo, por la que se fijan las especies pescables, los periodos hábiles de pesca y las aguas en que se puede llevar a cabo la actividad de la pesca en las aguas continentales de Cataluña durante la temporada 2013.
Diari Oficial de la Generalitat de Catalunya (DOGC), 2013b. Resolució AAM/2291/2013, de 30 d'octubre, per la qual es fixa com a mesura de control del cargol poma (Pomacea sp.) el tractament amb aigua de mar i l'assecament hivernal de determinades zones del Delta de l'Ebre.
Diari Oficial de la Generalitat de Catalunya (DOGC), 2014. Resolución AAM/413/2014, de 13 de febrero, por la que se fijan las especies pescables, los periodos hábiles de pesca y las aguas en las que se puede llevar a cabo la actividad de la pesca en las aguas continentales de Cataluña durante la temporada 2014.

Diario de un Pescador, 2011. La Generalitat de Catalunya quiere eliminar la obligatoriedad de la catalogación de zonas de pesca sin muerte en las reservas genéticas [WWW Document]. URL http://diariodeunpescador.wordpress.com/2011/06/09/la-generalitat-de-catalunya-quiere-eliminar-la-obligatoriedad-de-la-catalogacion-de-zonas-de-pesca-sin-muerte-en-las-reservas-geneticas/ (accessed 4.9.14).
Direcció General del Medi Natural (DGMN), 2005. Estratègia Catalana de Lluita contra el Musclo Zebra. Barcelona.
Dittmer, K., 2008. Zebra mussel invasion management: Exploring the discrepancies between recreational users and the Ebro River basin authority. Master thesis, Autonomous University of Barcelona, Bellaterra.
Dittmer, K., Rodriguez-Labajos, B., 2009. Socio-environmental impacts of the invasive *Dreissena polymorpha* (zebra mussel) in the Ebro River Ebro River, European Conference of Conservation Biology. European Conference of Conservation Biology, September 2, 2009, Prague.
Doadrio, I., 2002. Atlas y libro rojo de los peces continentales de España. Dirección General de Conservación de la Naturaleza: Museo Nacional de Ciencias Naturales, Madrid.
Doadrio, I., Aldeguer, M., 2007. La invasion de especies exóticas en los ríos. Work. Pap. Spanish Strateg. Rivers' Restoration, Minist. Medio Ambient. Univ. Politécnica Madrid.
Doğan Bora, N., Gül, A., 2003. Feeding biology of *Silurus glanis* (L., 1758) living in HirfanlÝ Dam Lake. Turkish J. Vet. Anim. Sci. 28, 471–479.
Dolfsma, W., Verburg, R., 2005. Bridging structure and agency: Processes of institutional change.
Ehrlich, P.R., Ehrlich, A.H., Holdren, J.P., 1977. Ecoscience: Population, Resources, Environment, W.H. Freeman and Company. San Francisco.
Elder Jr, G.H., 1994. Time, human agency, and social change: Perspectives on the life course. Soc. Psychol. Q. 4–15.
Elliott, M., 2003. Biological pollutants and biological pollution--an increasing cause for concern. Mar. Pollut. Bull. 46, 275–280.
Elton, C.S., 1958. The ecology of invasions by animals and plants. Chapman and Hall, London.
Elvira, B., 2001. Identification of non-native freshwater fishes established in Europe and assessment of their potential threats to the biological diversity. Strasbourg.
Eritja, R., Escosa, R., Lucientes, J., Marques, E., Roiz, D., Ruiz, S., 2005. Worldwide invasion of vector mosquitoes: present european distribution and challenges for Spain. Biol. Invasions 7, 87–97.
Esteva, G., Prakash, M.S., 2004. From global to local: Beyond neoliberalism to the international of hope, in: Lechner, F.J. (Ed.), The Globalisation Reader. pp. 410–416.
Europa Press, 2013. El Govern confinarà el cargol poma en el marge esquerre del Delta de l'Ebre.
European and Mediterranean Plant Protection Organization (EPPO), 2008. Data sheets on quarantine pests. Eichhornia crassipes. OEPP/EPPO Bull. 38, 441–449.
European Centre for Disease Prevention and Control (ECDC), 2013. Environmental risk mapping: Aedes albopictus in Europe. Stockholm.
European Commission (EC), 2003a. Common implementation strategy for the Water Framework Directive (2000/60/EC). Guidance Document No 5. Transitional and Coastal Waters – Typology, Reference Conditions and Classification Systems. Office for the Official Publications of the European Communities, Luxembourg.
European Commission (EC), 2003b. Common implementation strategy for the Water Framework Directive (2000/60/EC). Guidance document No. 3. Analysis of Pressures and Impacts. Office for the Official Publications of the European Communities, Luxembourg.
European Commission (EC), 2003c. Common implementation Strategy for the Water Framework Directive (2000/60/EC). Guidance document No. 10. River and lakes – Typology, reference conditions and classification system. Working Group 2.3. REFCOND. Office for the Official Publications of the European Communities, Luxembourg.
European Commission (EC), 2008. Towards an EU Strategy on Invasive Species. EC, Brussels 2008.
European Commission (EC). Environment, 2014. Invasive Alien Species. Commission proposal for EU legislation to address invasive alien species and protect biodiversity [WWW Document]. URL http://ec.europa.eu/environment/nature/invasivealien/index_en.htm (accessed 4.2.14).
European Commission (EC-DGXI), 1996. Vision 2020: Scenarios for a Sustainable Europe. General Consultative Forum, European Commission, Directorate General XI, Environment, Nuclear Safety and Civil Protection, Brussels.
European Commission (EC-DGXVII), 1996. Energy in Europe: European Energy to 2020: A Scenario Approach. European Commission, Luxembourg.

European Environment Agency (EEA), 2009. Looking back on looking forward. A review on evaluative scenario literature. Copenhagen.
European Environment Agency (EEA), 2010. Towards an early warning and information system for invasive alien species (IAS) threatening biodiversity in Europe. Copenhagen.
European Environment Agency (EEA), 2012. Invasive alien species indicators in Europe. A review of streamlining European biodiversity (SEBI) Indicator 10. Luxembourg.
European Environment Agency (EEA), 2014a. DPSIR [WWW Document]. Environ. Terminol. Discov. Serv. URL http://glossary.eea.europa.eu/terminology/concept_html?term=dpsir (accessed 4.1.14).
European Environment Agency (EEA), 2014b. Indicators and fact sheets about Europe's environment [WWW Document]. Environ. Top. URL http://www.eea.europa.eu/data-and-maps/indicators/
European Parliament, 2014a. Invasive alien species: MEPs reach agreement with the Greek Presidency [WWW Document]. News. URL http://www.europarl.europa.eu/news/en/news-room/content/20140304IPR37510/html/Invasive-alien-species-MEPs-reach-agreement-with-the-Greek-Presidency (accessed 4.15.14).
European Parliament, 2014b. Answer given by Mr Potočnik on behalf of the Commission (E-013129/2013) [WWW Document]. Parliam. Quest. 30 January 2014. URL http://www.europarl.europa.eu/sides/getAllAnswers.do?reference=E-2013-013129&language=EN#def2 (accessed 4.12.14).
Evans, E.A., 2003. Economic dimensions of invasive species. CHOICES. A Publ. Am. Agric. Econ. Assoc. Second Qua, 5–9.
Farrell, K.N., 2011. Snow White and the wicked problems of the West: A look at the lines between empirical description and normative prescription. Sci. Technol. Human Values.
Fernández Cebrián, R., 2011. Estructura poblacional y demografía genética en poblaciones de trucha común (Salmo trutta) del Pirineo catalán. Universitat de Girona.
Fernández-Delgado, C., 2013. Erradicación de la carpa (*Cyprinus carpio*) de la Reserva Natural de Zóñar, in: Jornadas Sobre Especies Invasoras de Ríos Y Zonas Húmedas. Técnicas de Control Y Gestión. Consorci de l'Estany, Banyoles, p. 45.
Fieser, E., 2009. How Guatemala's most beautiful lake turned ugly. Time.
Flinkman, J., Backer, H., 2003. Fishes of the Northern Baltic, Baltic Sea Portal [WWW Document]. URL http://www.fimr.fi/en/itamerikanta/bsds/722.html (accessed 4.25.05).
Flyvbjerg, B., 2001. Making social science matter: why social inquiry fails and how it can succeed again. Cambridge University Press, Cambridge.
Food and Agriculture Organization of the United Nations (FAO), 2000. Multilateral trade negotiations on agriculture. A resource manual. III. Agreement on the Application of Sanitary and Phytosanitary Measures (SPS) and Agreement on Technical Barriers to Trade (TBT) [WWW Document]. URL http://www.fao.org/docrep/003/x7354e/x7354e00.htm
Foro Nuclear, 2011. Spanish suclear industry. Spanish Nuclear Industry Forum, Madrid.
Freixe, G. de N., Jiménez Ruiz, P.J., 2002. Localització i avaluació de l'extensió de la invasió biológica per musclo zebra (*Dreissena polymorpha*) a l'Ebre [Localization and evaluation of the zebra mussel biological invasion spread in the Ebro]. Generalitat de Catalunya , Departament de Medi Ambient, Direcció General de Boscos i Biodiversitat, Flix.
Fullbrook, E., 2002. Intersubjectivity in Economics: Agents and Structures. Routledge, London.
Funtowicz, S.O., Ravetz, J.R., 1990. Uncertainty and quality in science for policy. Kluwer Academic Publishers, Dordrecht, The Netherlands.
Funtowicz, S.O., Ravetz, J.R., 1994. The worth of a songbird: ecological economics as a post-normal science. Ecol. Econ.
Galil, B.S., 2000. A sea under siege–alien species in the Mediterranean. Biol. Invasions 2, 177–186.
Gallardo, B., Aldridge, D.C., 2013. Priority setting for invasive species management: risk assessment of Ponto-Caspian invasive species into Great Britain. Ecol. Appl. 23, 352–64. doi:10.1890/12-1018.1
Gallardo, B., Errea, M., Aldridge, D., 2012. Application of bioclimatic models coupled with network analysis for risk assessment of the killer shrimp, *Dikerogammarus villosus*, in Great Britain. Biol. Invasions In press, 1–14. doi:10.1007/s10530-011-0154-0
Galli, P., Stefani, F., Benzoni, F., Crosa, G., Zullini, A., 2003. New records of alien monogeneans from *Lepomis gibbosus* and *Silurus glanis* in Italy. Parassitologia 45, 147–149.
Gallopin, G., Hammond, A., Raskin, P., Swart, R., 1997a. Global scenarios and human choice. Stock. Environ. Institute.ISBN 91, 88714.

Gallopin, G., Hammond, A., Raskin, P., Swart, R., 1997b. Branch points: Global scenarios and human choice. Stockholm Environment Institute-Global Scenario Group, Boston.
Gallopin, G.C., Rijsberman, F., 2000. Three global water scenarios. Int. J. Water 1, 16–40.
Galt, M., Tait, D., Chicoine-Piper, M., 1997. Idon Scenario Thinking: how to navigate the uncertainties of unknown futures. Idea Group, U.S.
García-Berthou, E., Alcaraz, C., Pou-Rovira, Q., Zamora, L., Coenders, G., Feo, C., 2005. Introduction pathways and establishment rates of invasive aquatic species in Europe. Can. J. Fish. Aquat. Sci.
Gassó Pérez-Portabella, N., 2008. Plant invasion success in Spain: A macroecological approach. CREAF-Autonomous University of Barcelona, Bellaterra.
GEF-UNDP-IMO GloBallast Partnerships Programme, WMU, 2013. Identifying and managing risks from organisms carried in ships' ballast water. London and Malmö.
Genovesi, P., 2005. Eradications of invasive alien species in Europe: a review. Issues Bioinvasion Sci. 1995, 127–133. doi:10.1007/1-4020-3870-4_12
Genovesi, P., Shine, C., 2004. European strategy on invasive alien species. Strasbourg.
Gergs, R., Rothhaupt, K.-O., 2008. Feeding rates, assimilation efficiencies and growth of two amphipod species on biodeposited material from zebra mussels. Freshw. Biol. 53, 2494–2503. doi:10.1111/j.1365-2427.2008.02077.x
Gettys, L.A., Haller, W.T., Bellaud, M., 2009. Biology and control of aquatic plants: A best management practices handbook. Aquatic Ecosystem Restoration Foundation, Marietta, Georgia.
Giacobbe, M.G., Penna, A., Gangemi, E., Masò, M., Garcés, E., Fraga, S., Bravo, I., Azzaro, F., Penna, N., 2007. Recurrent high-biomass blooms of Alexandrium taylorii (Dinophyceae), a HAB species expanding in the Mediterranean. Hydrobiologia 580, 125–133.
Gibson, C.C., Ostrom, E., Ahn, T.K., 2000. The concept of scale and the human dimensions of global change: a survey. Ecol. Econ. 32, 217–239. doi:10.1016/S0921-8009(99)00092-0
Gido, K.B., Schaefer, J.F., Pigg, J., 2004. Patterns of fish invasions in the Great Plains of North America. Biol. Conserv. 118, 121–131.
Gilbert, M., Grégoire, J.C., Freise, J.F., Heitland, W., 2004. Long-distance dispersal and human population density allow the prediction of invasive patterns in the horse chestnut leafminer Cameraria ohridella. J. Anim. Ecol. 73, 459–468.
Glaser, B.G., Strauss, A.L., 1967. The discovery of grounded theory. Int. J. Qual. Methods 5, 1–10. doi:10.2307/588533
Gordon, D.R., Onderdonk, D.A., Fox, A.M., Stocker, R.K., 2008. Consistent accuracy of the Australian weed risk assessment system across varied geographies. Divers. Distrib. 14, 234–242. doi:10.1111/j.1472-4642.2007.00460.x
Green, P.T., O'Dowd, D.J., Abbott, K.L., Jeffery, M., Retallick, K., Mac Nally, R., 2011. Invasional meltdown: Invader–invader mutualism facilitates a secondary invasion. Ecology. doi:10.1890/11-0050.1
Greeuw, S.C.H., Asselt, M.B.A. van, Grosskurth, J., Storms, C.A.M.H., Rijkens-Klomp, N., Rothman, D., Rotmans, J., 2000. Cloudy crystal balls: an assessment of recent European and global scenario studies and models. , Environmental Issues Series 17, European Environmental Agency, Copenhagen.
Gregory, R., Long, G., 2009. Using structured decision making to help implement a precautionary approach to endangered species management. Risk Anal.
Grigorovich, I.A., Therriault, T.W., MacIsaac, H.J., 2003. History of aquatic invertebrate invasions in the Caspian Sea. Biol. Invasions 5, 103–115.
Grimalt, J.O., Sánchez-Cabeza, J.A., Palanques, A., Catalan, J., 2003. Estudi de la dinàmica dels compostos organoclorats persistents i altres contaminants en els sistemas aquàtics continentals. Barcelona.
Groote, H.D. de, Ajuonu, O., Attignon, S., Djessou, R., Neuenschwander, P., 2003. Economic impact of biological control of water hyacinth in Southern Benin. Ecol. Econ. 45, 105–117.
Grosholz, E.D., 2005. Recent biological invasion may hasten invasional meltdown by accelerating historical introductions. Proc. Natl. Acad. Sci. U. S. A. 102, 1088–1091.
Grupo de Especies Invasoras (GEI), 2010. Plataforma Catálogo Español de EEI [WWW Document]. URL https://sites.google.com/site/plataformacatalogoespanoldeeei/
Guha, R., 2000. Environmentalism: a global history. Oxford University Press, Delhi.
Haberl, H., Schulz, N.B., Plutzar, C., Erb, K.H., Krausmann, F., Loibl, W., Moser, D., Sauberer, N., Weisz, H., Zechmeister, H.G., 2004. Human appropriation of net primary production and species diversity in agricultural landscapes. Agric. Ecosyst. Environ. 102, 213–218.
Hammer, M., Gilek, M., 2012. Towards improved environmental risk governance of the Baltic Sea. Huddinge, Sweden.

Haugom, G.P., Behrens, H.L., Andersen, A.B., 2002. Risk based-methodology to assess invasive aquatic species in ballast water, in: Leppäkosk, E., Gollasch, S., Olenin, S. (Eds.), Invasive Aquatic Species of Europe Distribution, Impact and Management. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 467–476.
Heger, T., Trepl, L., 2003. Predicting biological invasions. Biol. Invasions 5, 313–321.
Hellmann, J.J., Byers, J.E., Bierwagen, B.G., Dukes, J.S., 2008. Five potential consequences of climate change for invasive species. Conserv. Biol. 22, 534–543. doi:10.1111/j.1523-1739.2008.00951.x
Hendriks, C.M., Grin, J., 2007. Contextualizing Reflexive Governance: the Politics of Dutch Transitions to Sustainability. J. Environ. Policy Plan.
Herborg, L.M., Rushton, S.P., Clare, A.S., Bentley, M.G., 2003. Spread of the Chinese mitten crab (*Eriocheir sinensis* H. Milne Edwards) in Continental Europe: analysis of a historical data set. Hydrobiologia 503, 21–28.
Hernandez, M., Iyengar, S.S., 2001. What drives whom? A cultural perspective on human agency. Soc. Cogn. 19, 269–294.
Hil, M., Baker, R., Broad, G., Chandler, P.J., Copp, G.H., Ellis, J., Jones, D., Hoyland, C., Laing, I., Longshaw, M., Moore, N., Parrott, D., Pearman, D., Preston, C., Smith, R.M., Waters, R., 2005. Audit of non-native species in England. Peterborough, UK.
Hodgson, G.M., 2004. The evolution of institutional economics: agency, structure and Darwinism in American institutionalism. Routledge, London and New York.
Holmgren, M., 2002. Exotic herbivores as drivers of plant invasion and switch to ecosystem alternative states. Biol. Invasions 4, 25–33.
Horppila, J., Kairesalo, T., 1992. Impacts of bleak (<i>Alburnus alburnus<i>) and roach (*Rutilus rutilus*) on water quality, sedimentation and internal nutrient loading. Hydrobiologia 243, 323–331.
Hulme, P.E., 2006. Beyond control: wider implications for the management of biological invasions. J. Appl. Ecol. 43, 835–847.
Hulme, P.E., 2008. Biological invasions in Europe: drivers, pressures, states, impacts and responses. Issues Environ. Sci. Technol. 25, 56–80.
Hulme, P.E., 2012. Weed risk assessment: a way forward or a waste of time? J. Appl. Ecol. 49, 10–19. doi:10.1111/j.1365-2664.2011.02069.x
Hulme, P.E., Bacher, S., Kenis, M., Klotz, S., Kühn, I., Minchin, D., Nentwig, W., Olenin, S., Panov, V., Pergl, J., 2008. Grasping at the routes of biological invasions: a framework for integrating pathways into policy. J. Appl. Ecol. 45, 403–414.
Hulme, P.E., Pyšek, P., Nentwig, W., Vilà, M., 2009. Will threat of biological invasions unite the European Union. Science (80-.). 324, 40–41.
Ibáñez, C., Prat Fornells, N., Duran, C., Pardos, M., Munné Torrás, A., Andreu, R., Caiola, N.M., Cid, N., Hampel, H., Sánchez, R., 2008. Changes in dissolved nutrients in the lower Ebro river: Causes and consequences. Limnetica 27, 131–142.
Ibeas, M., 2012. Cargol poma: Desgràcia per a molts i beneficis multimilionaris per a pocs [WWW Document]. indirecte! URL http://in.directe.cat/marc-ibeas/blog/9315/cargol-poma-desgracia-per-a-molts-i-beneficis-multimilionaris-per-a-pocs/imprimir (accessed 4.11.14).
Ibeas, M., 2013. El caragol maçana fa trontollar part de les polítiques de desenvolupament rural comunitàries. l'Ebre.
Institut Cartogràfic de Catalunya (ICC), 2014. Website of the Institut Cartogràfic de Catalunya [WWW Document]. URL www.icc.cat (accessed 4.16.14).
Intergovernmental Panel on Climate Change (IPCC), 2007. Climate Change, Fourth Assessment Report. Cambridge University Press, Cambridge.
IPCC, 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland.
Jeschke, J.M., Gomez Aparicio, L., Haider, S., Heger, T., Lortie, C., Pyšek, P., Strayer, D., 2012. Support for major hypotheses in invasion biology is uneven and declining. NeoBiota 14.
Jiménez, B., 2009. Victoria parcial de los pueblos indígenas de Perú. El Mundo.
Johnson, L.E., Padilla, D.K., 1996. Geographic spread of exotic species: ecological lessons and opportunities from the invasion of the zebra mussel *Dreissena polymorpha*. Biol. Conserv. 78, 23–33.
Jukes, A., Wade, M., Ames, V., McKee, K., 2011. Canadian and Nuttall's Waterweeds. Species description: Elodea species [WWW Document]. GB Non-Native Species Secr.

Junta de Andalucía, 2012. La Junta de Andalucía confirma la presencia de mejillón cebra en el embalse de Iznájar [WWW Document]. URL http://www.juntadeandalucia.es/medioambiente/site/portalweb/menuitem.30d4b35a97db5c61716f2b105510e1ca/?vgnextoid=e4693374f1609310VgnVCM2000000624e50aRCRD&vgnextchannel=2229b8f8606b8210VgnVCM10000055011eacRCRD (accessed 4.14.14).
Kadirbeyoğlu, Z., 2004. The transnational dimension of the Bergama campaign against Eurogold, in: Faist, T. (Ed.), Transnational Social Spaces: Agents, Networks and Institutions. Ashgate Pub Ltd, p. 37.
Kahn, H., Wiener, A.J., 1967. Year 2000. A Framework for speculation on the next thirty-three years. MacMillan, New York.
Karatayev, A.Y., Burlakova, L.E., Padilla, D.K., Johnson, L.E., 2003. Patterns of spread of the zebra mussel (*Dreissena polymorpha* (Pallas)): the continuing invasion of Belarussian lakes. Biol. Invasions 5, 213–221.
Karatayev, A.Y., Padilla, D.K., Minchin, D., Boltovskoy, D., Burlakova, L.E., 2007. Changes in global economies and trade: the potential spread of exotic freshwater bivalves. Biol. Invasions 9, 161–180.
Karr, J.R., 1981. Assessment of Biotic Integrity Using Fish Communities. Fisheries. doi:10.1577/1548-8446(1981)006<0021:AOBIUF>2.0.CO;2
Karr, J.R., 1987. Biological monitoring and environmental assessment: a conceptual framework. Environ. Manage. doi:10.1007/BF01867203
Kasemir, B., Jager, J., Jaeger, C.C., Gardner, M.T., 2003. Public participation in sustainability science: a handbook. Cambridge University Press, Cambridge, UK.
Keller, R.P., Lake, P.S., 2007. Potential impacts of a recent and rapidly spreading coloniser of Australian freshwaters: Oriental weatherloach (Misgurnus anguillicaudatus). Ecol. Freshw. Fish 16, 124–132.
Kennard, M.J., Arthington, A.H., Pusey, B.J., Harch, B.D., 2005. Are alien fish a reliable indicator of river health? Freshw. Biol. 50, 174–193. doi:PDF 4
Kloskowski, J., 2011. Impact of common carp <I>Cyprinus carpio</I> on aquatic communities: direct trophic effects versus habitat deterioration. Fundam. Appl. Limnol. / Arch. für Hydrobiol.
Kobayakawa, M., 1989. Systematic revision of the catfish genus *Silurus*, with description of a new species from Thailand and Burma. Japanese J. Ichthyol. 36, 155–186.
Koehn, J.D., 2010. Carp (*Cyprinus carpio*) as a powerful invader in Australian waterways. Freshw. Biol. 49, 882–894. doi:PDF 3 & 133
Kok, K., Patel, M., Rothman, D.S., Quaranta, G., 2006a. Multi-scale narratives from an IA perspective: Part II. Participatory local scenario development. Futures 38, 285–311.
Kok, K., Rothman, D.S., Patel, M., 2006b. Multi-scale narratives from an IA perspective: Part I. European and Mediterranean scenario development. Futures 38, 261–284.
Kolar, C.S., Lodge, D.M., 2001. Progress in invasion biology: predicting invaders. Trends Ecol. Evol. 16, 199–204.
Köprücü, S.Ş., Köprücü, K., Ural, M.Ş., Ispir, Ü., Pala, M., 2006. Acute toxicity of organophosphorous pesticide diazinon and its effects on behavior and some hematological parameters of fingerling European catfish (Silurus glanis L.). Pestic. Biochem. Physiol. 86, 99–105.
Kowalski, K., Stagl, S., Madlener, R., Omann, I., 2009. Sustainable energy futures: Methodological challenges in combining scenarios and participatory multi-criteria analysis. Eur. J. Oper. Res. 197, 1063–1074.
Kowarik, I., 2003. Human agency in biological invasions: secondary releases foster naturalisation and population expansion of alien plant species. Biol. Invasions 5, 293–312.
Kraft, C.E., Sullivan, P.J., Karatayev, A.Y., Burlakova, L.E., Nekola, J.C., Johnson, L.E., Padilla, D.K., 2002. Landscape patterns of an aquatic invader: assessing dispersal extent from spatial distributions. Ecol. Appl. 12, 749–759.
Kraus, F., Campbell, E.W., 2002. Human-mediated escalation of a formerly eradicable problem: the invasion of Caribbean frogs in the Hawaiian Islands. Biol. Invasions 4, 327–332.
Kuhn, T.S., 1970. The Structure of Scientific Revolutions, Philosophical Review, SO Source: University of Chicago Press: Chicago. (1962). University of Chicago Press. doi:10.1119/1.1969660
Lang, A., Cooney, R., 2009. Taking uncertainty seriously: Adaptive governance and international trade: A rejoinder to Mónica García-Salmones. Eur. J. Int. Law 20, 187–192.
Le Maitre, D., Reyers, B., King, N., 2002. National core set of environmental indicators. Phase 3: selection of indicators. Biodiversity and natural heritage Report. National Department of Environmental Affairs and Tourism, Pretoria.
Le Maitre, D.C., Richardson, D.M., Chapman, R.A., 2004. Alien plant invasions in South Africa: driving forces and the human dimension. S. Afr. J. Sci. 100(1), 103–112.

Lebel, L., Thongbai, P., Kok, K., Agard, J.B.R., Bennett, E.M., Biggs, R., Ferreira, M., Filer, C., Gokhale, Y., Mala, W., Rumsey, C., Velarde, S.J., Zurek, M., Blanco, H., Lynam, T., Tianxiang, Y., 2005. Sub-global scenarios, in: Capistrano, D., Lee, M., Raudsepp-Hearne, C., Samper, C. (Eds.), Ecosystems and Human Well-Being: Multiscale Assessments. Island Press, Washington, D.C., pp. 229–259.

Lee, A., 2009. ECOSTAT workshop on alien species and the EC Water Framework Directive. Final Report. Ispra, Italy.

Levine, J.M., D'Antonio, C.M., 2003. Forecasting biological invasions with increasing international trade. Conserv. Biol. 17, 322–326.

Ihan, A., 2009. Social movements in sustainability transitions. Identity, social learning and power in the Spanish and Turkish water domains, PhD Thesis, Autonomous University of Barcelona. PhD Thesis, Autonomous University of Barcelona, Bellaterra (Cerdanyola del Vallès).

Liu, S., Hurley, M., Lowell, K.E., Siddique, A.-B.M., Diggle, A., Cook, D.C., 2011. An integrated decision-support approach in prioritizing risks of non-indigenous species in the face of high uncertainty. Spec. Sect. - Earth Syst. Gov. Account. Legitimacy 70, 1924–1930. doi:10.1016/j.ecolecon.2011.05.021

Llançó, J.M., 2003. Records de la construcció de l'embassament de Sau, in: Sanmartín, F.X. (Ed.), El Ter. Un Riu Compartit. Lunwerg; Aigües del Ter-Llobregat, pp. 21–38.

Lonsdale, W.M., 1999. Global patterns of plant invasions and the concept of invasibility. Ecology 80, 1522–1536.

López, M.A., 2012. Cargol Poma: quines actuacions pot fer l'arrosser? [WWW Document]. Dep. d'Agricultura, Ramadaria, Pesca i Medi Nat. General. Catalunya. URL http://www.recercat.net/bitstream/handle/2072/207586/10_Caragol Poma.pdf?sequence=17 (accessed 4.11.14).

López, M.A., Ruiz-Altaba, C., Andree, K.B., López, V., 2010. First invasion of the apple snail Pomacea insularum in Europe. Tentacle 18, 26–28.

López Soriano, J., Quiñorero Salgado, S., Tarruella, A., 2009. Presencia masiva de *Pomacea cf. canaliculata* (Lamarck, 1822) (Gastropoda: Ampullariidae) en el Delta del Ebro (Cataluña, España). Spira. Assoc. Catalana Malacol. 3, 117–121.

Lundgren, M.R., Small, C.J., Dreyer, G.D., 2004. Influence of land use and site characteristics on invasive plant abundance in the Quinebaug Highlands of southern New England. Northeast. Nat. 11, 313–332.

MacIsaac, H.J., Grigorovich, I.A., Ricciardi, A., 2001. Reassessment of species invasions concepts: the Great Lakes basin as a model. Biol. Invasions 3, 405–416.

MacNeil, C., Briffa, M., Leuven, R.S.E.W., Gell, F.R., Selman, R., 2010. An appraisal of a biocontamination assessment method for freshwater macroinvertebrate assemblages; a practical way to measure a significant biological pressure? Hydrobiologia.

Madeira García, M.J., Ayala Puelles, I., Razkin Agurre, O., Reyes Moreno, R., 2012. Evaluación del impacto causado por el mejillón cebra (*Dreissena polymorpha*) sobre las poblaciones de bivalvos autóctonos en la cuenca del río Arratia y en los embalses de Urrúnaga y y Ullíbarri-Gamboa. Asociación para la Conservación y Estudio de la Biodiversidad (ACEBI) - URA, Vitoria-Gasteiz.

Magee, T.K., Ringold, P.L., Bollman, M.A., Ernst, T.L., 2010. Index of alien impact: a method for evaluating potential ecological impact of alien plant species. Environ. Manage. 45, 759–778. doi:10.1007/s00267-010-9426-1

Maguire, L.A., 2004. What can decision analysis do for invasive species management? Risk Anal. 24(4), 859–868.

Malseed, K., 2008. Where there is no movement: Local resistance and the potential for solidarity. J. Agrar. Chang. 8, 489–514.

Martinez-Alier, J., Anguelovski, I., Bond, P., Del Bene, D., Demaria, F., Gerber, J.F., Greyl, L., Haas, W., Healy, H., Marín-Burgos, V., Ojo, G., Porto, M., Rijnhout, L., Rodríguez-Labajos, B., Spangenberg, J., Temper, L., Warlenius, R., Yánez, I., 2014. Between activism and science: Grassroots concepts for sustainability coined by environmental justice organizations. J. Polit. Ecol. 21, 19–60.

Martinez-Alier, J., Healy, H., Temper, L., Walter, M., Rodriguez-Labajos, B., Gerber, J.-F., Conde, M., 2011. Between science and activism: learning and teaching ecological economics with environmental justice organisations. Local Environ. doi:10.1080/13549839.2010.544297

Masip, M., Rofes, J., 2003. Localització geogràfica i ecològica de la invasió de *Dreissena polymorpha* en el tram de l'Ebre comprès entre l'embassament de Mequinensa i la desembocadura. Grup de Natura Freixe / Consorci per a la Protecció Integral del Delta de l'Ebre (CPIDE), Flix.

Matsuda, H., 2002. Challenges posed by the precautionary principle and accountability in ecological risk assessment. Environmetrics 14, 245–254. doi:10.1002/env.581

Maxim, L., Spangenberg, J.H., O'Connor, M., 2009. An analysis of risks for biodiversity under the DPSIR framework. Ecol. Econ. 69, 12–23.
McConnachie, M.M., Cowling, R.M., van Wilgen, B.W., McConnachie, D.A., 2012. Evaluating the cost-effectiveness of invasive alien plant clearing: A case study from South Africa. Biol. Conserv. 155, 128–135.
McKinney, M.L., 2002. Influence of settlement time, human population, park shape and age, visitation and roads on the number of alien plant species in protected areas in the USA. Divers. Distrib. 8, 311–318.
McKinney, M.L., 2006. Correlated non-native species richness of birds, mammals, herptiles and plants: scale effects of area, human population and native plants. Biol. Invasions 8, 415–425.
McNeely, J.A., 2001. The great reshuffling: human dimensions of invasive alien species. World Conservation Union-UICN, Gland, Switzerland and Cambridge.
Meinesz, A., Belsher, T., Thibaut, T., Antolic, B., Mustapha, K.B., Boudouresque, C.F., Chiaverini, D., Cinelli, F., Cottalorda, J.M., Djellouli, A., 2001. The introduced green alga *Caulerpa taxifolia* continues to spread in the Mediterranean. Biol. Invasions 3, 201–210.
Meinesz, A., Javel, F., Cottalorda, J.M., 2003. Suivi de l'invasion des algues *Caulerpa taxifolia* et *Caulerpa racemosa* en Méditerranée : situation devant les côtes françaises et monégasques fin 2003. Université Nice-Sophia Antipolis, LEML publ., Nice.
Melville, E.G.K., 1997. A plague of sheep: environmental consequences of the conquest of Mexico, Studies in Environmental History. Cambridge University Press, Cambridge.
Mihulka, S., Pyšek, P., 2001. Invasion history of Oenothera congeners in Europe: a comparative study of spreading rates in the last 200 years. J. Biogeogr. 28, 597–609.
Millan, M., 2014. Descens espectacular els peixos presents als canals de l'Ebre. D. Tarragona.
Millennium Ecosystem Assessment (MA), 2003. Ecosystems and Human Wellbeing: A Framework for Assessment. Island Press, Washington, D.C.
Millennium Ecosystem Assessment (MA), 2005a. Ecosystems and Human Well-being: Synthesis (Millennium Ecosystem Assessment), Ecosystems, Millenium Assessments. World Resources Institute. doi:10.1196/annals.1439.003
Millennium Ecosystem Assessment (MA), 2005b. Ecosystems and human well-being. Biodiversity synthesis, Synthesis. World Resources Institute, Washington D.C.
Miller, D.A.W., Weir, L.A., McClintock, B.T., Grant, E.H.C., Bailey, L.L., Simons, T.R., 2012. Experimental investigation of false positive errors in auditory species occurrence surveys. Ecol. Appl. doi:10.1890/11-2129.1
Minchin, D., Gollasch, S., 2002. Vectors – how exotics get around, in: Leppäkoski, E. (Ed.), Invasive Aquatic Species of Europe: Distribution Impacts and Management. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 206–216.
Ministerio de Agricultura Alimentación y Medio Ambiente (MAGRAMA), 2014a. Inventario de presas y embalses (SNCZI-IPE) [WWW Document]. Sist. Nac. Cartogr. Zo. Inundables. URL http://sig.magrama.es/snczi/visor.html?herramienta=DPHZI (accessed 4.14.14).
Ministerio de Agricultura Alimentación y Medio Ambiente (MAGRAMA), 2014b. Listado de Especies Silvestres en Régimen de Protección Especial y Catálogo Español de Especies Amenazadas [WWW Document]. URL http://www.magrama.gob.es/es/biodiversidad/temas/conservacion-de-especies-amenazadas/catalogo-nacional-de-especies-amenazadas/ (accessed 4.14.14).
Ministerio de Medio Ambiente (MMA), 2007. El Ministerio y las Comunidades Autónomas se reunieron en la Conferencia Sectorial de Medio Ambiente. Ambienta 70, 54–58.
Mollenkopf, J., 2003. How to study urban political power, in: Le Gates, R., Stout, F. (Eds.), The City Reader. Routledge, London and New York, pp. 235–244.
Monterroso, I., Binimelis, R., Rodríguez-Labajos, B., 2010. New methods for the analysis of invasion processes: Multi-criteria evaluation of the invasion of *Hydrilla verticillata* in Guatemala. J. Environ. Manage. 92, 494–507. doi:10.1016/j.jenvman.2010.09.017
Mooij, R. de, Tang, P., 2003. Four futures of Europe. CBP Centraal Planbureau, Den Haag, the Netherlands.
Mooney, H.A., Ehrlich, P.R., 1997. Ecosystem services: a fragmentary history, in: Daily, G.C. (Ed.), Nature's Services. Societal Dependence on Natural Ecosystems. Island Press, Washington D.C and Covelo, California, pp. 11–19.
Morton, A.D., 2002. La Resurrección del Maíz': Globalisation, Resistance and the Zapatistas. Millenn. Int. Stud. 31, 27–54.

Munné, A., Prat, N., 2009. Use of macroinvertebrate-based multimetric indices for water quality evaluation in Spanish Mediterranean rivers: An intercalibration approach with the IBMWP index. Hydrobiologia 628, 203–225.
Narščius, A., Olenin, S., Zaiko, A., Minchin, D., 2012. Biological invasion impact assessment system: From idea to implementation. Ecol. Inform. 7, 46–51.
Nehring, S., Klingenstein, F., 2008. Aquatic alien species in Germany – Listing system and options for action, in: Rabitsch, W., Essl, F., Klingenstein, F. (Eds.), Biological Invasions – from Ecology to Conservation. NEOBIOTA 7. pp. 19–33.
Nentwig, W., Kühnel, E., Bacher, S., 2010. A generic impact-scoring system applied to alien mammals in Europe. Conserv. Biol. 24, 302–311. doi:10.1111/j.1523-1739.2009.01289.x
Noronha, L., Lourenco, N., Lobo-Ferreira, J., Lleopart, A., 2002. Coastal tourism, environment and sustainable development. TERI Publications, New Delhi.
Nowotny, H., Leroy, P., 2009. Helga Nowotny: an itinerary between sociology of knowledge and public debate. Interview by Pieter Leroy. Natures Sci. Sociétés 17, 57–64.
Nyberg, C.D., Wallentinus, I., 2005. Can species traits be used to predict marine macroalgal introductions? Biol. Invasions 7, 265–279.
Official Journal of the European Communities (OJEC), 1992. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.
Official Journal of the European Communities (OJEC), 1997. Council Regulation (EC) No 338/97 of 9 December 1996 on the protection of species of wild fauna and flora by regulating trade therein.
Official Journal of the European Communities (OJEC), 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.
Official Journal of the European Union (OJEU), 2007. Council Regulation (EC) No 708/2007 of 11 June 2007 concerning use of alien and locally absent species in aquaculture.
Official Journal of the European Union (OJEU), 2008a. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy.
Official Journal of the European Union (OJEU), 2008b. Commission Regulation (EC) No 506/2008 of 6 June 2008 amending Annex IV to Council Regulation (EC) No 708/2007 concerning use of alien and locally absent species in aquaculture.
Official Journal of the European Union (OJEU), 2010. Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds.
Official Journal of the European Union (OJEU), 2011. Regulation (EU) No 304/2011 of the European Parliament and the Council of 9 March 2011 amending Council Regulation (EC) No 708/2007 concerning use of alien and locally absent species in aquaculture.
Official Journal of the European Union (OJEU), 2012. Commission Implementing Decision of 8 November 2012 as regards measures to prevent the introduction into and the spread within the Union of the genus Pomacea (Perry) (notified under document C(2012) 7803) (2012/697/EU).
Olenin, S., Alemany, F., Cardoso, A.C., Gollasch, S., Goulletquer, P., Lehtiniemi, M., McCollin, T., Minchin, D., Miossec, L., Occhipinti Ambrogi, A., Ojaveer, H., Jensen, K.R., Stankiewicz, M., Wallentinus, I., Aleksandrov, B., 2010. Marine Strategy Framework Directive – Task Group 2 Report. Non-indigenous Species. Office for Official Publications of the European Communities, Luxembourg. doi:10.2788/87092
Olenin, S., Elliott, M., Bysveen, I., Culverhouse, P.F., Daunys, D., Dubelaar, G.B.J., Gollasch, S., Goulletquer, P., Jelmert, A., Kantor, Y., Mézeth, K.B., Minchin, D., Occhipinti-Ambrogi, A., Olenina, I., Vandekerkhove, J., 2011. Recommendations on methods for the detection and control of biological pollution in marine coastal waters. Mar. Pollut. Bull.
Olenin, S., Minchin, D., Daunys, D., 2007. Assessment of biopollution in aquatic ecosystems. Mar. Pollut. Bull. 55, 379–394.
Olenina, I., Wasmund, N., Hajdu, S., Jurgensone, I., Gromisz, S., Kownacka, J., Toming, K., Vaiciute, D., Olenin, S., 2010. Assessing impacts of invasive phytoplankton: The Baltic Sea case. Mar. Pollut. Bull. 60, 1691–1700.
Omann, I., Stocker, A., Jäger, J., 2009. Climate change as a threat to biodiversity: An application of the DPSIR approach. Ecol. Econ. 69, 24–31.
Onderdonk, D. a, Gordon, D.R., Fox, A.M., Stocker, R.K., 2010. Lessons learned from testing the Australian weed risk assessment system : the devil is in the details. Plant Prot. Q. 25, 79–86.

Öniş, Z., Şenses, F., 2007. Global dynamics, domestic coalitions and a reactive state: major policy shifts in post-war Turkish economic development. METU Stud. Dev. 34, 251–286.
Ordeix, M., Solà, C., Bardina, M., Casamitjana, A., Munné, A., 2010. Els peixos dels rius i zones humides de Catalunya. Qualitat biològica i connectivitat fluvial. Agència Catalana de l'Aigua, Departament de Medi Ambient i Habitatge, Generalitat de Catalunya, Barcelona.
Özkaynak, B., 2008. Globalisation and local resistance: Alternative city developmental scenarios on capital's global frontier-the case of Yalova, Turkey. Prog. Plann. 70, 45–97.
Özkaynak, B., Rodríguez-Labajos, B., 2010. Multi-scale interaction in local scenario-building: A methodological framework. Futures 42, 995–1006.
Palau, A., Cía, I., 2006. Métodos de control y erradicacion del mejillón cebra (*Dreissena polymorpha*) [Methods for zebra mussel eradication and control]. Dirección de Medio Ambiente y Desarrollo Sostenible Endesa.
Palau, A., Durán, C., Romeo, R., 2008. Vulnerabilidad de las masas de agua frente al mejillón cebra. Ing. del Agua 15, 265–280.
Panov, V., Dgebuadze, Y., Shiganova, T., Filippov, A., Minchin, D., 2007. A risk assessment of biological invasions in the inland waterways of Europe: the Northern Invasion Corridor case study. Biol. invaders Inl. waters Profiles, Distrib. Threat. 639–656.
Panov, V.E., Alexandrov, B., Arbaciauskas, K., Binimelis, R., Copp, G.H., Grabowski, M., Lucy, F., Leuven, R.S.E.W., Nehring, S., Paunović, M., Semenchenko, V., Son, M.O., 2009. Assessing the risks of aquatic species invasions via European inland waterways: from concepts to environmental indicators. Integr. Environ. Assess. Manag. 5, 110–126.
Pauchard, A., Alaback, P.B., 2004. Influence of elevation, land use, and landscape context on patterns of alien plant invasions along roadsides in protected areas of south-central Chile. Conserv. Biol. 18, 238–248.
Pérez Pons, M., 2012. La Generalitat acusará a la empresa que introdujo el caracol manzana en el Ebro. El País-Catalunya.
Pérez y Pérez, L., Chica Moreu, C., 2006. Estimación de los costes económicos de la invasión del mejillón cebra (<i>Dreissena polymorpha>) en la Cuenca del Ebro [Estimation of economic costs of the zebra mussel invation in the Ebro basin]. Fund. Econ. Aragon. (FUNDEAR), Doc. Trab. 35/2006, 1–48.
Pérez y Pérez, L., Chica Moreu, C., 2010. Actualización de la valoración económica de la invasión del mejillón cebra en la cuenca del Ebro [Update of the economic valuation of the zebra mussel invasion in the Ebro River basin], Fundación Economía Aragonesa (FUNDEAR), Documento de trabajo. Confederación Hidrográfica del Ebro, Zaragoza.
Pérez-Bote, J.L., Roso, R., 2009. First record of the European catfish *Silurus glanis* Linnaeus, 1758 (Siluriformes, Siluridae) in the Alcántara reservoir (Tagus basin, Spain). An. Biol. 59–60.
Perrings, C., 2005. Mitigation and adaptation strategies for the control of biological invasions. Ecol. Econ. 52, 315–325.
Perrings, C., Williamson, M., Barbier, E.B., Delfino, D., Dalmazzone, S., Shogren, J., Simmons, P., Watkinson, A., 2002. Biological invasion risks and the public good: an economic perspective. Conserv. Ecol.
Peterson, G.D., Beard, T.D.J., Beisner, B.E., Bennett, E.M., Carpenter, S.R., Cumming, G.S., Dent, C.L., Havlicek, T.D., 2003. Assessing Future Ecosystem Services : a Case Study of the Northern Highlands Lake District , Wisconsin. Conserv. Ecol. 7, 1. doi:Artn 1
Pheloung, P.C., Williams, P. a, Halloy, S.R., 1999. A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. J. Environ. Manage. 57, 239–251.
Pienimäki, M., Leppäkoski, E., 2004. Invasion pressure on the Finnish Lake District: invasion corridors and barriers. Biol. Invasions 6, 331–346.
Pimentel, D., Lach, L., Zunica, R., Morrison, D., 2000. Environmental and economic costs of nonindigenous species in the United States. Bioscience 50(1), 53–65.
Pimentel, D., Zuniga, R., Morrison, D., 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecol. Econ. 52, 273–288.
Pino, J., Font, X., Carbo, J., Jové, M., Pallares, L., 2005. Large-scale correlates of alien plant invasion in Catalonia (NE of Spain). Biol. Conserv. 122, 339–350.
Pinto, L., Chandrasena, N., Pera, J., Hawkins, P., Eccles, D., Sim, R., 2005. Managing invasive carp (*Cyprinus carpio* L.) for habitat enhancement at Botany Wetlands, Australia. Aquat. Conserv. Mar. Freshw. Ecosyst. 15, 447–462. doi:10.1002/aqc.684
Pohlmann, K., Grasso, F.W., Breithaupt, T., 2001. Tracking wakes: the nocturnal predatory strategy of piscivorous catfish. Proc. Natl. Acad. Sci. 98, 7371.
Portal informatiu 3-24, 2008. Plataforma en Defensa de l'Ebre: "El govern no està gestionant la sequera amb honestedat" [WWW Document]. Actualitat. URL

http://www.324.cat/noticia/265789/catalunya/Plataforma-en-Defensa-de-lEbre-El-govern-no-esta-gestionant-la-sequera-amb-honestedat (accessed 4.17.14).
Possum, 1998. Policy Scenarios for Sustainable Mobility. Final Report ST-96-SC.107.
Pou-Rovira, Q., Campos, M., Feo, C., 2013. LIFE "Projecte Estany". Resultados de más de tres años de control poblacional de peces exóticos, in: Jornadas Sobre Especies Invasoras de Ríos Y Zonas Húmedas. Técnicas de Control Y Gestión. Consorci de l'Estany, Banyoles, p. 48.
Pyšek, P., Jaroík, V., Kuera, T., 2002. Patterns of invasion in temperate nature reserves. Biol. Conserv. 104, 13–24.
Pyšek, P., Prach, K., 1995. Invasion dynamics of Impatiens glandulifera - a century of spreading reconstructed. Biol. Conserv. 74, 41–48.
Pyšek, P., Prach, K., 2003. Research into plant invasions in a crossroads region: history and focus. Biol. Invasions 5, 337–348.
Pyšek, P., Richardson, D.M., 2010. Invasive species, environmental change and management, and health. Annu. Rev. Environ. Resour. 35, 25–55. doi:10.1146/annurev-environ-033009-095548
Pyšek, P., Richardson, D.M., Williamson, M., 2004. Predicting and explaining plant invasions through analysis of source area floras: some critical considerations. Divers. Distrib. 10, 179–187.
Rauschmayer, F., 2003. Integrated assessment of biological invasions as a base for biodiversity policies, in: BIOECON International Conference of Economic Analysis of Policies for Biodiversity Conservation.
Ravetz, J., 2000. Integrated assessment for sustainability appraisal in cities and regions. Environ. Impact Assess. Rev. 20, 31–64.
Ravetz, J.R., 1971. Scientific knowledge and its social problems. Clarendon Press, Oxford.
Ray, C., 1999. Towards a meta-framework of endogenous development: Repertoires, paths, democracy and rights. Sociol. Ruralis 39, 522–537.
Reading, A.J., Britton, J.R., Davies, G.D., Shinn, A.P., Williams, C.F., 2011. Introduction and spread of non-native parasites with *Silurus glanis* L. (Teleostei: Siluridae) in UK fisheries. J. Helminthol.
Ricciardi, A., 2001. Facilitative interactions among aquatic invaders: is an" invasional meltdown" occurring in the Great Lakes? Can. J. Fish. Aquat. Sci. 58, 2513–2525.
Richardson, M.J., Whoriskey, F.G., Roy, L.H., 1995. Turbidity generation and biological impacts of an exotic fish Carassius auratus, introduced into shallow seasonally anoxic ponds. J. Fish Biol. 47, 576–585.
Rittel, H.W.J., Webber, M.M., 1973. Dilemmas in a general theory of planning. Policy Sci. 4, 155–169.
Robbins, P., 2004. Comparing invasive networks: cultural and political biographies of invasive species. Geogr. Rev. 94, 139–156.
Rodríguez-Labajos, B., 2006. Interlinked biological invasions in the Ebro River. A multi-scale scenario approach. Master dissertation. Autonomous University of Barcelona, Bellaterra (Cerdanyola del Vallès).
Rodríguez-Labajos, B., 2013. Climate change, ecosystem services, and costs of action and inaction: scoping the interface. Wiley Interdiscip. Rev. Clim. Chang. 4, 555–573. doi:10.1002/wcc.247
Rodríguez-Labajos, B., Binimelis, R., Cardona, C., Dittmer, K., Martínez-Alier, J., Monterroso, I., Munné, A., 2010. Chronicle of a Bioinvasion Foretold: Distribution and management of the zebra mussel (*Dreissena polymorpha*) invasion in Spain, in: Settele, J. (Ed.), Atlas of Biodiversity Risk. Pensoft, Sofia, pp. 198–201.
Rodríguez-Labajos, B., Binimelis, R., Monterroso, I., 2009a. Multi-level driving forces of biological invasions. Ecol. Econ. 69, 63–75.
Rodríguez-Labajos, B., Binimelis, R., Monterroso, I., Martinez-Alier, J., 2009b. The arrival of Dreissena polymorpha and Silurus glanis in the Ebro River: Socio-economics of interlinked aquatic bioinvasions, in: Rodriguez-Labajos, B. (Ed.), Assessing Biodiversity Risks with Socio-Economic Methods: The ALARM Experience. Pensoft, Sofia, pp. 69–111.
Rodriguez-Labajos, B., Dittmer, K., 2009. Socio-environmental impacts of the invasive *Dreissena polymorpha* (zebra mussel) in the Ebro River Ebro River, in: ESEE Conference, June 30, 2009. Ljubljana.
Rodríguez-Labajos, B., Martínez-Alier, J., 2013. The economics of ecosystems and biodiversity: Recent instances for debate. Conserv. Soc. 11, 326–342. doi:10.4103/0972-4923.125744
Rodríguez-Labajos, B., Spangenberg, J.H., Maxim, L., Martinez-Alier, J., Binimelis, R., Gallai, N., Kuldna, P., Peterson, K., Uustal, M., 2009. Assessing biodiversity risks with socio-economic methods: The ALARM Experience. Pensoft, Sofia.
Rogelj, J., Meinshausen, M., Knutti, R., 2012. Global warming under old and new scenarios using IPCC climate sensitivity range estimates. Nat. Clim. Chang. doi:10.1038/nclimate1385
Ros, J., 2004. In memory of Ramon Margalef (1919-2004). Int. Microbiol. 7, 229–232.
Rotmans, J., van Asselt, M., Anastasi, C., Greeuw, S., Mellors, J., Peters, S., Rothman, D., Rijkens, N., 2000. Visions for a sustainable Europe. Futures 32, 809–831.

Roura-Pascual, N., Richardson, D.M., Chapman, R.A., Hichert, T., Krug, R.M., 2011. Managing biological invasions: charting courses to desirable futures in the Cape Floristic Region RID A-1495-2008. Reg. Environ. Chang. 11, 311–320. doi:10.1007/s10113-010-0133-5
Royo, R., 2009. Un nou mol·lusc invasor amenaça ara el conreu de l'arròs al delta de l'Ebre (11/08/09). El Punt - Avui.
Royo, R., 2011. La lluita contra el cargol poma indigna als caçadors. El Punt -Avui 39.
Ruiz, G.M., Fofonoff, P.W., Carlton, J.T., Wonham, M.J., Hines, A.H., 2000. Invasion of coastal marine communities in North America: apparent patterns, processes, and biases. Annu. Rev. Ecol. Syst. 31, 481–531.
Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M., Wall, D.H., 2000. Global biodiversity scenarios for the year 2100. Science (80-.). 287, 1770–1774. doi:10.1126/science.287.5459.1770
Sala, O.E., Chapin, F.S.I.I.I., Gardner, R.H., Lauenroth, W.K., Mooney, H.A., Ramakrishnan, P.S., 1999. Global change, biodiversity and ecological complexity, in: Walker, B.H.W. (Ed.), The Terrestrial Biosphere and Global Change: Implications for Natural and Managed Ecosystems. Cambridge University Press, Cambridge, pp. 304–328.
Sandvik, H., Sæther, B.-E., Holmern, T., Tufto, J., Engen, S., Roy, H.E., 2013. Generic ecological impact assessments of alien species in Norway: a semi-quantitative set of criteria. Biodivers. Conserv. 22, 37–62.
Sanz Elorza, M., Sobrino Vesperinas, E., Sánchez, D., 2004. Atlas de las plantas alóctonas invasoras en España.
Schlaepfer, M.A., Sax, D.F., Olden, J.D., 2011. The potential conservation value of non-native species. Conserv. Biol. 25, 428–437. doi:10.1111/j.1523-1739.2010.01646.x
Schmitz, D.C., Simberloff, D., 1997. Biological invasions: a growing threat. Issues Sci. Technol. 13, 33–40.
Scholes, R., Settele, J., Betts, R., Bunn, S., Leadley, P., Nepstad, D., Overpeck, J., Taboada, M.A., Allen, C., Anderegg, W., Bellard, C., Brando, P., Courchamp, F., Foden, W., Gerten, D., Goetz, S., Golding, N., Gonzalez, P., Hawkins, E., Hickler, T., Hurtt, G., Koven, C., Lawler, J., Lischke, H., Mace, G., McGeoch, M., Parmesan, C., Pearson, R., Rodriguez-Labajos, B., Rondinini, C., Shaw, R., Sitch, S., Tockner, K., Visconti, P., Winter, M., 2014. Chapter 4. Terrestrial and Inland Water Systems, in: Intergovernmental Panel on Climate Change (IPCC) (Ed.), Climate Change 2014: Impacts, Adaptation, and Vulnerability (IPCC WGII AR5). Stanford, CA, USA, p. 153.
Schütz, H., Bringezu, S., Moll, S., 2004. Globalisation and the shifting environmental burden. Material trade flows of the European Union, Wuppertal Papers. Wuppertal Institute for Climate, Environment, Energy, Wuppertal.
Sekulova, F., Kallis, G., Rodríguez-Labajos, B., Schneider, F., 2013. Degrowth: From theory to practice. J. Clean. Prod. 38, 1–6.
Settele, J., Carter, T.R., Kühn, I., Spangenberg, J.H., Sykes, M.T., 2012. Scenarios as a tool for large-scale ecological research: experiences and legacy of the ALARM project. Glob. Ecol. Biogeogr. 21, 1–4. doi:10.1111/j.1466-8238.2011.00720.x
Sharov, A.A., 2004. Bioeconomics of managing the spread of exotic pest species with barrier zones. Risk Anal. 24, 879–892.
Shiklomanov, I., 1993. World fresh water resources, in: Gleick, P.H. (Ed.), Water in Crisis: A Guide to the World's Fresh Water Resources. Oxford University Press, New York, pp. 13–24.
Shine, C., Kettunen, M., Genovesi, P., Essl, F., Gollasch, S., Rabitsch, W., Scalera, R., Starfinger, U., ten Brink, P., 2010. Assessment to support continued development of the EU Strategy to combat invasive alien species. Final Report for the European Commission.
Shmelev, S.E., Rodríguez-Labajos, B., 2009. Dynamic multidimensional assessment of sustainability at the macro level: The case of Austria. Ecol. Econ. 68, 2560–2573.
Šidagyte, E., Višinskiene, G., Arbačiauskas, K., 2013. Macroinvertebrate metrics and their integration for assessing the ecological status and biocontamination of Lithuanian lakes. Limnologica 43, 308–318.
Simberloff, D., 2005. The politics of assessing risk for biological invasions: the USA as a case study. Trends Ecol. Evol. 20, 216–222.
Simberloff, D., Gibbons, L., 2004. Now you see them, now you don't!–population crashes of established introduced species. Biol. Invasions 6, 161–172.
Simberloff, D., Parker, I.M., Windle, P.N., 2005. Introduced species policy, management, and future research needs. Front. Ecol. Environ. 3, 12–20. doi:10.1890/1540-9295(2005)003[0012:ispmaf]2.0.co;2
Simberloff, D., Von Holle, B., 1999. Positive interactions of nonindigenous species: invasional meltdown? Biol. Invasions 1, 21–32.

Sol, D., Timmermans, S., Lefebvre, L., 2002. Behavioural flexibility and invasion success in birds. Anim. Behav. 63, 495–502.
Sostoa, A. de, Caiola, N.M., Casals, F., García-Berthou, E., Alcaraz, C., Benejam, L., Maceda, A., Solà, C., Munné, A., 2010. Ajust de l'índex d'Integritat Biòtica (IBICAT) basat en l'ús dels peixos com a indicadors de la qualitat ambiental als rius de Catalunya. Agència Catalana de l'Aigua, Departament de Medi Ambient i Habitatge, Generalitat de Catalunya, Barcelona.
Sostoa, A. de, Caiola, N.M., Vinyoles, D., Sánchez, S., Franch, C., Casals, F., 2003. Desenvolupament d'un índex d'integritat biòtica (IBICAT) basat en l'ús dels peixos com a indicadors de la qualitat ambiental dels rius de Catalunya. Aplicació de la Directiva marc en política d'aigües de la Unió Europea (2000/60/CE). Informe final del Dep. Departament de Medi Ambient, Generalitat de Catalunya., Barcelona.
Sousa, R., Morais, P., Dias, E., Antunes, C., 2011. Biological invasions and ecosystem functioning: time to merge. Biol. Invasions 1–4.
Spangenberg, J.H., 2007. Biodiversity pressure and the driving forces behind. Ecol. Econ. 61, 146–158.
Spangenberg, J.H., Bondeau, A., Carter, T.R., Fronzek, S., Jaeger, J., Jylhä, K., Kühn, I., Omann, I., Paul, A., Reginster, I., Rounsevell, M., Schweiger, O., Stocker, A., Sykes, M.T., Settele, J., 2012. Scenarios for investigating risks to biodiversity. Glob. Ecol. Biogeogr. 21, 5–18. doi:10.1111/j.1466-8238.2010.00620.x
Stern, N.H., Peters, S., Bakhshi, V., Bowen, A., Cameron, C., Catovsky, S., Crane, D., Cruickshank, S., Dietz, S., Edmondson, N., Garbett, S.-L., Hamid, L., Hoffman, G., Ingram, D., Jones, B., Patmore, N., Radcliffe, H., Sathiyarajah, R., Stock, M., Taylor, C., Vernon, T., Wanjie, H., Zenghelis, D., 2006. Stern Review: The economics of climate change. Office—HMTreasury, Cambridge University Press, Cambridge, UK.
Stewart, T.J., French, S., Rios, J., 2013. Integrating multicriteria decision analysis and scenario planning-Review and extension. Omega (United Kingdom) 41, 679–688.
Stirling, A., 2007. Risk, precaution and science: towards a more constructive policy debate. EMBO Rep. 8, 309–315.
Stirling, A., 2010. Addressing uncertainty, ambiguity and ignorance in sustainability appraisal, in: Interdiciplinary Workshop on 'Cost-Benefit Analysis: Uncertainty, Discouinting and the Sustainability Future. Technical University Eindhoven, Eindhoven, Netherlands, p. 40.
Stirling, A., Leach, M., Mehta, L., Scoones, I., Smith, A., Stagl, S., Thompson, J., 2007. Empowering designs: towards more progressive appraisal of sustainability. Brighton.
Stohlgren, T.J., Schnase, J.L., 2006. Risk analysis for biological hazards: what we need to know about invasive species. Risk Anal. 26, 163–173. doi:10.1111/j.1539-6924.2006.00707.x
Stratigea, A., Giaoutzi, M., 2012. Linking global to regional scenarios in foresight. Futures 44, 847–859.
Strayer, D.L., 2010. Alien species in fresh waters: ecological effects, interactions with other stressors, and prospects for the future. Freshw. Biol. 55, 152–174.
Sytsma, M.D., Cordell, J.R., Chapman, J.W., Draheim, R.C., 2004. Lower Columbia River aquatic nonindigenous species survey 2001-2004. Final technical report.
Syväranta, J., Cucherousset, J., Kopp, D., Crivelli, A., Céréghino, R., Santoul, F., 2010. Dietary breadth and trophic position of introduced European catfish *Silurus glanis* in the River Tarn (Garonne River basin), southwest France. Aquat. Biol.
Taylor, B.W., Irwin, R.E., 2004. Linking economic activities to the distribution of exotic plants. Proc. Natl. Acad. Sci. U. S. A. 101, 17725–17730.
Taylor, C., 2007. Cultures of democracy and citizen efficacy. Public Cult. 19, 117–150.
Taylor, E., Lycett, E., 2008. Freshwater non-native species management initiatives. Peterborough, UK.
Telenotícies TV3, 2009. Emissió del "Telenotícies migdia", corresponent al dilluns 10 d'agost del 2009 (27:16-29:07) [WWW Document]. URL http://www.tv3.cat/videos/1423789/TN-migdia-10082009 (accessed 4.10.14).
Thresher, R., Proctor, C., Ruiz, G., Gurney, R., MacKinnon, C., Walton, W., Rodriguez, L., Bax, N., 2003. Invasion dynamics of the European shore crab, *Carcinus maenas*, in Australia. Mar. Biol. 142, 867–876.
Tricarico, E., 2012. A review on pathways and drivers of use regarding non-native freshwater fish introductions in the Mediterranean region. Fish. Manag. Ecol. 19, 133–141. doi:10.1111/j.1365-2400.2011.00834.x
Tricarico, E., Vilizzi, L., Gherardi, F., Copp, G.H., 2010. Calibration of FI-ISK, an invasiveness screening tool for nonnative freshwater invertebrates. Risk Anal. 30, 285–292.
Trotarríos, 2009. Manifiesto d'Anglès. Girona dice no a la Llei de Pesca [WWW Document]. URL http://trotarrios.blogspot.com.es/2009/12/en-contra-de-la-nueva-ley-de-pesca-en.html (accessed 4.9.14).
U.S. Fish and Wildlife Service, 2014. 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.

UK Biodiversity Partnership Standing Committee, 2003. Summary report of the 2nd full meeting of UK Biodiversity Research Advisory Group (BRAG). The Royal Botanic Gardens, Edinburgh.
Underwood, A.J., Chapman, M.G., 2003. Power, precaution, Type II error and sampling design in assessment of environmental impacts. J. Exp. Mar. Bio. Ecol. 296, 49–70. doi:10.1016/S0022-0981(03)00304-6
United Nations (UN), 2010. General Assembly declares access to clean water and sanitation is a human right. UN News Cent.
United Nations Environment Programme (UNEP), 2002. Global Environment Outlook 3 (GEO-3): Past, present and future perspectives. Earthscan publications, London and Steirling, VA.
United Nations Environment Programme (UNEP), 2007. Global Environmentl Outlook 4 (GEO-4): Environment for development. UNEP, Progress Press, Valetta, Malta.
United States Congress. Office of Technology Assessment (US OTA), 1993. Harmful non-indigenous species in the United States. U.S. Government Printing Office, Washington D.C.
Ur Agentzia (URA), 2014. Situación del Mejillón Cebra en la Comunidad Autónoma del País Vasco [WWW Document]. URL http://www.uragentzia.euskadi.net/u81-0003/es/contenidos/informacion/mejillon_cebra/es_doc/mapas.html (accessed 4.14.14).
Urkidi, L., 2008. Movimientos anti-mineros: el caso de Pascua-Lama en Chile. Rev. Iberoam. Econ. Ecológica 8, 63–77.
Valldepérez, S., 2004. Natros! Gent i identitat de les Terres de l'Ebre [Us! Terres de l'Ebre's People and Identity]. Editorial Pòrtic, Capellades.
Van Notten, P.W.F., Rotmans, J., van Asselt, M., Rothman, D.S., 2003. An updated scenario typology. Futures 35, 423–443.
Van Vliet, M., Kok, K., 2007. New concepts for development of integrated multi-scale scenarios within the SCENES project, in: CAIWA, Proceedings of the International Conference on Adaptive & Integrated Water Management, Coping with Complexity and Uncertainty. Basel, Switzerland.
Vandekerkhove, J., Cardoso, A.C., 2010. Alien species and the Water Framework Directive. Questionnaire results. European Commission - JRC Scientific and Technical Reports, Ispra, Italy.
Vandekerkhove, J., Cardoso, A.C., Boon, P.J., 2013. Is there a need for a more explicit accounting of invasive alien species under the Water Framework Directive ? Manag. Biol. Invasions 4, 25–36. doi:http://dx.doi.org/10.3391/mbi.2013.4.1.04
Verbrugge, L.N.H., Leuven, R.S.E.W., Velde, G. van der, 2010. Evaluation of international risk assessment protocols for exotic species. Department of Environmental Science, Faculty of Science, Radboud University Nijmegen, Nijmegen, the Netherlands.
Videira, N., Antunes, P., Santos, R., Lopes, R., 2010. A participatory modelling approach to support integrated sustainability assessment processes. Syst. Res. Behav. Sci. 27, 446–460. doi:10.1002/sres.1041
Vilà, M., Basnou, C., Pyšek, P., Josefsson, M., Genovesi, P., Gollasch, S., Nentwig, W., Olenin, S., Roques, A., Roy, D., 2009. How well do we understand the impacts of alien species on ecosystem services? A pan-European, cross-taxa assessment. Front. Ecol. Environ. 8, 135–144.
Vilà, M., Pino, J., Font, X., 2007. Regional assessment of plant invasions across different habitat types. J. Veg. Sci. 18, 35–42.
Vila, M., Pujadas, J., 2001. Land-use and socio-economic correlates of plant invasions in European and North African countries. Biol. Conserv. 100, 397–401.
Vitousek, P.M., D'antonio, C.M., Loope, L.L., Rejmanek, M., Westbrooks, R., 1997. Introduced species: a significant component of human-caused global change. N. Z. J. Ecol. 21, 1–16.
Voß, J., Bornemann, B., 2011. The politics of reflexive governance: challenges for designing adaptive management and transition management. Ecol. Soc. 16, 9.
Walker, B., Carpenter, S., Anderies, J., Abel, N., Cumming, G., Janssen, M., Lebel, L., Norberg, J., Peterson, G.D., Pritchard, R., 2002. Resilience management in social-ecological systems: a working hypothesis for a participatory approach. Conserv. Ecol. 6, 14.
Walker, P.A., 2006. Political ecology: where is the policy? Prog. Hum. Geogr.
Walpole, M., Almond, R.E.A., Besancon, C., Butchart, S.H.M., Campbell-Lendrum, D., Carr, G.M., Collen, B., Collette, L., Davidson, N.C., Dulloo, E., Fazel, A.M., Galloway, J.N., Gill, M., Goverse, T., Hockings, M., Leaman, D.J., Morgan, D.H.W., Revenga, C., Rickwood, C.J., Schutyser, F., Simons, S., Stattersfield, A.J., Tyrrell, T.D., Vie, J.-C., Zimsky, M., 2009. Tracking Progress Toward the 2010 Biodiversity Target and Beyond. Science (80-.). 325, 1503–1504.
Walter, M., Martinez-Alier, J., 2010. How to be heard when nobody wants to listen: community action against mining in Argentina. Can. J. Dev. Stud. Can. d'études du développement 30, 281–301.

Waters, R., 2004. Invasive Non-Native Species: Discussion paper [WWW Document]. English Nature, Gen. Comm. Counc. GC P04 52. URL http://www.english-nature.org.uk/about/meetings/ /GCP0452a.pdf (accessed 12.5.05).
Weber, E., 1998. The dynamics of plant invasions: a case study of three exotic goldenrod species (*Solidago* L.) in Europe. J. Biogeogr. 25, 147–154.
Weber, J., Dane Panetta, F., Virtue, J., Pheloung, P., 2009. An analysis of assessment outcomes from eight years' operation of the Australian border weed risk assessment system. J. Environ. Manage. 90, 798–807.
Wehrmeyer, W., Clayton, A., Ngubane, B., 2003. Foresighting for development. Earthscan, London.
Westphal, M.I., Browne, M., MacKinnon, K., Noble, I., 2008. The link between international trade and the global distribution of invasive alien species. Biol. Invasions 10, 391–398.
Whinam, J., Chilcott, N., Bergstrom, D.M., 2005. Subantarctic hitchhikers: expeditioners as vectors for the introduction of alien organisms. Biol. Conserv. 121, 207–219.
Wiek, A., Binder, C., Scholz, R.W., 2006. Functions of scenarios in transition processes. Futures 38, 740–766. doi:10.1016/j.futures.2005.12.003
Williams, S.L., Grosholz, E.D., 2008. The invasive species challenge in estuarine and coastal environments: Marrying management and science. Estuaries and Coasts.
Williamson, M., 1999. Invasions. Ecography (Cop.). 22, 5–12.
Wittenberg, R., Cock, M.J.W., 2001. Invasive alien species: a toolkit of best prevention and management practices. CABInternational on behalf GISP, Wallingford, Oxon, UK.
Wittfoth, A.K.J., Zettler, M.L., 2013. The application of a Biopollution Index in German Baltic estuarine and lagoon waters. Manag. Biol. Invasions 4, 43–50.
Wolfenbarger, L.L., 2000. The ecological risks and benefits of genetically engineered plants. Science (80-.). 290, 2088.
Worner, S.P., Gevrey, M., 2006. Modelling global insect pest species assemblages to determine risk of invasion. J. Appl. Ecol. 43, 858–867.
WWF, 2008. Living Planet Report 2008. Banson Production and WWF Cambridge, Gland, Switzerland.
WWF, 2010. Living Planet Report 2010. Biodiversity, biocapacity and development. Gland, Switzerland.
Wynne, B., 1992. Uncertainty and environmental learning. Reconceiving science and policy in the preventive paradigm. Glob. Environ. Chang. 2, 111–127.
Zaiko, A., Lehtiniemi, M., Narščius, A., Olenin, S., 2011. Assessment of bioinvasion impacts on a regional scale: a comparative approach. Biol. Invasions 13, 1739–1765.
Zografos, C., Martínez-Alier, J., 2009. The politics of landscape value: a case study of wind farm conflict in rural Catalonia. Environ. Plan. A 41, 1726–1744.
Zurek, M.B., Henrichs, T., 2007. Linking scenarios across geographical scales in international environmental assessments. Technol. Forecast. Soc. Change 74, 1282–1295.

Annexes

Annex I Municipalities supplied by the *ETAP del Ter* (2008)

Sources: (a) ATLL (2004); (b) IDESCAT (2010) (c) ATLL (2010). Note: Volumed supplied by ATLL, without distinguishing its orig in

Municipality [a]	Comarca [b]	Population (2009) [b]	Volume supplied by ATLL (m^3, 2008) [c]
Alella	Maresme	9 397	849.416
Argentona	Maresme	11 633	1.031.280
Badalona	Barcelonès	219 547	n.a.
Barberà del Vallès	Vallès Occidental	31 144	2.431.394
Barcelona	Barcelonès	1 621 537	(SGAB) 73.685.337; (SGAB) Fontana 12.252.763
Cabrera de Mar	Maresme	4 408	644.372
Cabrils	Maresme	6 964	786.614
Caldes d'Estrac	Maresme	2 799	285.001
Caldes de Montbui	Vallès Oriental	16 885	n.a.
Canovelles	Vallès Oriental	16 023	1.062.942
Cardedeu	Vallès Oriental	16 596	981.938
Cerdanyola del Vallès	Vallès Occidental	58 747	n.a.
Dosrius	Maresme	4 937	(acueduct) 773.789; (town) 574.734
El Masnou	Maresme	22 288	1.790.479
Granollers	Vallès Oriental	60 658	5.024.374
L'Ametlla del Vallès	Vallès Oriental	7 949	755.079
La Garriga	Vallès Oriental	14 991	1.055.032
La Llagosta	Vallès Oriental	13 820	112.220
La Roca del Vallès	Vallès Oriental	10 214	983.575
Les Franqueses del Vallès	Vallès Oriental	17 660	1.405.247
Lliçà d'Amunt	Vallès Oriental	14 143	864.795
Lliçà de Vall	Vallès Oriental	6 290	346.795
Llinars del Vallès	Vallès Oriental	9 035	23.813
Martorelles	Vallès Oriental	4 922	415.899 (Martorelles 2) 1.172.834
Mataró	Maresme	121 722	5.859.674
Mollet del Vallès	Vallès Oriental	52 484	3.083.648
Montcada i Reixac	Vallès Occidental	33 453	n.a.
Montgat	Maresme	10 270	n.a.
Montmeló	Vallès Oriental	8 955	640.992
Montornès del Vallès	Vallès Oriental	15 509	1.233.568
Orrius	Maresme	640	50.757
Palau-solità i Plegamans	Vallès Occidental	14 070	1.440.753
Parets del Vallès	Vallès Oriental	17 632	1.044.656
Polinyà	Vallès Occidental	7 676	576.362
Premià de Dalt	Maresme	9 944	721.583
Premià de Mar	Maresme	27 399	1.573.859
Ripollet	Vallès Occidental	37 088	2.346.819
Sabadell	Vallès Occidental	206 493	12.196.007
Sant Adrià de Besòs	Barcelonès	33 761	n.a.
Sant Andreu de Llavaneres	Maresme	10 181	1.048.010
Sant Antoni de Vilamajor (parcial)	Vallès Oriental	5 444	299.981
Sant Cugat del Vallès	Vallès Occidental	79 253	8.319.890
Sant Fost de Campsentelles	Vallès Oriental	8 234	611.002
Sant Pere de Vilamajor	Vallès Oriental	4 021	369.752
Sant Quize del Vallés	Vallès Occidental	18 462	551.052
Sant Vicenç de Montalt	Maresme	5 627	887.961
Sentmenat	Vallès Occidental	7 870	414.523
Sta. Coloma de Gramenet	Barcelonès	119 717	n.a.
Sta. Maria de Martorelles	Vallès Oriental	850	52.288
Sta. Maria de Palautordera	Vallès Oriental	8 823	162.028
Sta. Perpètua de Mogoda	Vallès Occidental	25 048	2.355.520
Teià	Maresme	6 087	472.914
Terrassa	Vallès Occidental	210 941	1.731.065; (Les Fonts) 222.836
Tiana	Maresme	7 590	457.874
Vallromanes	Vallès Oriental	2 283	241.319
Vilanova del Vallès	Vallès Oriental	4 654	315.283
Vilassar de Dalt	Maresme	8 672	758.391
Vilassar de Mar	Maresme	19 482	1.165.993

Annex II Questionnaires applied in the Ebro River to elicit economic costs of the zebra mussel invasion (2008)

Irrigation societies

Impactos del mejillón cebra en los sistemas de regadío

ENCUESTA A REGANTES

Presentación del cuestionario

Este cuestionario forma parte de las actividades de investigación por parte de la Universidad Autónoma de Barcelona en el marco del proyecto *Desarrollo de modelos y técnicas para la prevención y control del mejillón cebra*, financiado por el Ministerio de Medio Ambiente y Medio Rural y Marino. La información obtenida mediante el cuestionario es confidencial y será analizada únicamente por la Universidad Autónoma de Barcelona con fines científicos.

El objetivo del cuestionario es la evaluación de los impactos del mejillón cebra y apoyar al desarrollo de un plan de gestión.

Nombre y apellidos_____

Teléfono_____ Correo electrónico_____

Comunidad de regantes asociada_____

Cultivos_____

_____

1. ¿En qué medida ha observado la presencia de mejillón cebra en el sistema de regadío?

Captación: ☐ Alta (densidad considerable) ☐ Moderada (algunos ejemplares) ☐ Nula (no se observa)

Balsas: ☐ Alta (densidad considerable) ☐ Moderada (algunos ejemplares) ☐ Nula (no se observa)

Tuberías: ☐ Alta (densidad considerable) ☐ Moderada (algunos ejemplares) ☐ Nula (no se observa)

Hidrantes: ☐ Alta (densidad considerable) ☐ Moderada (algunos ejemplares) ☐ Nula (no se observa)

Otro (especificar debajo): ☐ Alta (densidad considerable) ☐ Moderada (algunos ejemplares) ☐ Nula (no se observa)

_____

Otro (especificar debajo): ☐ Alta (densidad considerable) ☐ Moderada (algunos ejemplares) ☐ Nula (no se observa)

_____

1

2. ¿La presencia de mejillón cebra en el sistema de regadío ha causado impactos negativos? Indique con "X", para cada año, la importancia atribuida a estos impactos.

	2001	2002	2003	2004	2005	2006	2007	2008
Impactos importantes								
Impactos moderados								
Impactos insignificantes								

3. ¿La presencia de mejillón cebra en el sistema de regadío se ha traducido en gastos económicos? Especifique, según tipo de gasto y año, el importe correspondiente en euros. En el caso de no conocerse el importe aproximado, indique gasto realizado con "X".

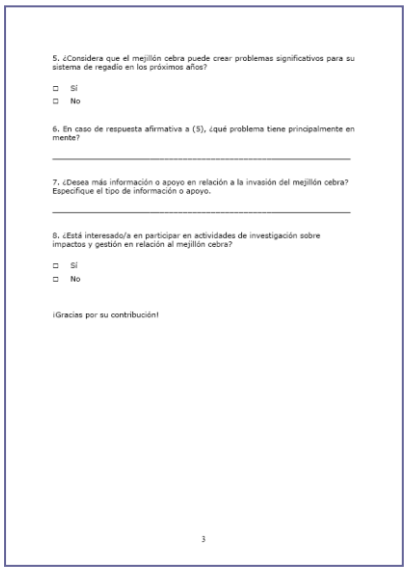
	2001	2002	2003	2004	2005	2006	2007	2008
GASTO TOTAL								
Sustitución rejas								
Sustitución bombas								
Sustitución válvulas								
Sustitución tuberías								
Sustitución hidrantes								
Tratamiento con cloro								
Tratamiento con pergamanato								
Instalación de filtros								
Gasto adicional de electricidad por eficacia de bombeo reducida								
Otro:_____								
Otro:_____								
Otro:_____								

4. ¿La presencia del mejillón cebra en el sistema de regadío ha causado impactos no económicos? Especifique cuáles.

_____

_____

2



5. ¿Considera que el mejillón cebra puede crear problemas significativos para su sistema de regadío en los próximos años?

☐ Sí
☐ No

6. En caso de respuesta afirmativa a (5), ¿qué problema tiene principalmente en mente?

_____

7. ¿Desea más información o apoyo en relación a la invasión del mejillón cebra? Especifique el tipo de información o apoyo.

_____

8. ¿Está interesado/a en participar en actividades de investigación sobre impactos y gestión en relación al mejillón cebra?

☐ Sí
☐ No

¡Gracias por su contribución!

3

Recreation and navigation

Mejillón cebra: Impactos y gestión

ENCUESTA A EMPRESAS DE OCIO ACUÁTICO Y DE CAMPING

Presentación del cuestionario

Este cuestionario forma parte de las actividades de investigación por parte de la Universidad Autónoma de Barcelona en el marco del proyecto *Desarrollo de modelos y técnicas para la prevención y control del mejillón cebra*, financiado por el Ministerio de Medio Ambiente y Medio Rural y Marino. La información obtenida mediante el cuestionario es confidencial y será analizada únicamente por la Universidad Autónoma de Barcelona con fines científicos.

El objetivo del cuestionario es la evaluación de los impactos del mejillón cebra y apoyar al desarrollo de un plan de gestión.

Nombre y apellidos_____

Empresa_____

Teléfono_____ Correo electrónico_____

I. EVALUACIÓN DE IMPACTOS DEL MEJILLÓN CEBRA

1. ¿Ha observado la presencia de mejillón cebra en las instalaciones de la empresa (embarcaderos, pantalanes, orilla)? Indique con "X", para cada año, la medida en que se ha observado.

	2001	2002	2003	2004	2005	2006	2007	2008
Alta (densidad considerable)								
Moderada (algunos ejemplares)								
Nula (no se observó)								

2. ¿Ha observado la presencia de mejillón cebra en las embarcaciones utilizadas? Indique con "X", para cada año, la medida en que se ha observado.

	2001	2002	2003	2004	2005	2006	2007	2008
Alta (densidad considerable)								
Moderada (algunos ejemplares)								
Nula (no se observó)								

1

3. ¿La presencia de mejillón cebra se traduce actualmente en alguno de los siguientes impactos para la empresa o sus usuarios? Indique la importancia atribuida a estos impactos:

Aplicación de pintura antifouling

☐ Impacto importante
☐ Impacto moderado
☐ Impacto insignificante Frecuencia ____ veces / año

Limpieza de embarcaciones (eliminación manual de mejillones, desinfección)

☐ Impacto importante
☐ Impacto moderado
☐ Impacto insignificante Frecuencia ____ veces / año

Miles de peces cortados

☐ Impacto importante
☐ Impacto moderado
☐ Impacto insignificante Frecuencia ____ veces / año

Menos horas de mejillones en estado de putrefacción

☐ Impacto importante
☐ Impacto moderado
☐ Impacto insignificante Frecuencia ____ veces / año

Otro, especifique: _____

☐ Impacto importante
☐ Impacto moderado
☐ Impacto insignificante Frecuencia ____ veces / año

4. ¿Considera que el mejillón cebra puede crear problemas significativos para la empresa en los próximos años?

☐ Sí
☐ No

5. En caso de respuesta afirmativa a (4), ¿qué problemas tiene principalmente en mente?

_____

2

6. ¿Cree que el problema del mejillón cebra y su gestión influye negativamente sobre la percepción de la zona como lugar de recreo que tienen los visitantes potenciales?

☐ Sí
☐ No

II. APOYO A LA GESTIÓN

Preguntas 7 y 8 sólo para campings

7. ¿Cuál es, aproximadamente, el tiempo de estancia medio de los visitantes del camping?

☐ Menos de una semana
☐ Una semana
☐ Dos semanas
☐ Un mes
☐ Más de un mes

8. Indique la proporción aproximada de embarcaciones en el camping que son propiedad de los visitantes (en proporción a la totalidad de embarcaciones en el camping)

☐ 0 %
☐ 1 - 25 %
☐ 25 - 50 %
☐ 50 - 75 %
☐ 75 - 100 %

9. ¿Desea más información o apoyo en relación a la invasión del mejillón cebra? Especifique el tipo de información o apoyo.

_____

10. ¿Está interesado/a en participar en actividades de investigación sobre impactos y gestión en relación al mejillón cebra?

☐ Sí
☐ No

¡Gracias por su contribución!

3

Local councils

Impactos del mejillón cebra

ENCUESTA A AYUNTAMIENTOS

Presentación del cuestionario

Este cuestionario forma parte de las actividades de investigación por parte de la Universidad Autónoma de Barcelona en el marco del proyecto *Desarrollo de modelos y técnicas para la prevención y control del mejillón cebra*, financiado por el Ministerio de Medio Ambiente y Medio Rural y Marino. La información obtenida mediante el cuestionario es confidencial y será analizada únicamente por la Universidad Autónoma de Barcelona con fines científicos.

El objetivo del cuestionario es la evaluación de los impactos del mejillón cebra y apoyar al desarrollo de un plan de gestión.

Nombre y apellidos_____

Ayuntamiento_____

Cargo_____

Teléfono_____ Correo electrónico_____

1. ¿Ha observado la presencia de mejillón cebra en las instalaciones de abastecimiento de agua potable del municipio? Indicar con "X", para cada año, la medida en que se ha observado.

	2001	2002	2003	2004	2005	2006	2007	2008
Alta (densidad considerable)								
Moderada (algunos ejemplares)								
Nula (no se observó)								

2. ¿Dónde se ha detectado mejillón cebra?

Captación: ☐ Alta (densidad considerable) ☐ Moderada (algunos ejemplares) ☐ Nula (no se observa)

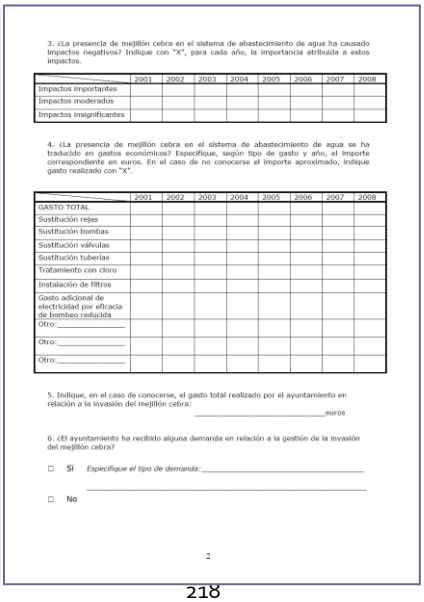
Depósitos: ☐ Alta (densidad considerable) ☐ Moderada (algunos ejemplares) ☐ Nula (no se observa)

Tuberías: ☐ Alta (densidad considerable) ☐ Moderada (algunos ejemplares) ☐ Nula (no se observa)

Otro (especificar debajo): ☐ Alta (densidad considerable) ☐ Moderada (algunos ejemplares) ☐ Nula (no se observa)

_____

1



3. ¿La presencia de mejillón cebra en el sistema de abastecimiento de agua ha causado impactos negativos? Indique con "X", para cada año, la importancia atribuida a estos impactos.

	2001	2002	2003	2004	2005	2006	2007	2008
Impactos importantes								
Impactos moderados								
Impactos insignificantes								

4. ¿La presencia de mejillón cebra en el sistema de abastecimiento de agua se ha traducido en gastos económicos? Especifique, según tipo de gasto y año, el importe correspondiente en euros. En el caso de no conocerse el importe aproximado, indique gasto realizado con "X".

	2001	2002	2003	2004	2005	2006	2007	2008
GASTO TOTAL								
Sustitución rejas								
Sustitución bombas								
Sustitución válvulas								
Sustitución tuberías								
Tratamiento con cloro								
Instalación de filtros								
Gasto adicional de electricidad por eficacia de bombeo reducida								
Otro:_____								
Otro:_____								
Otro:_____								

5. Indique, en el caso de conocerse, el gasto total realizado por el ayuntamiento en relación a la invasión del mejillón cebra: _____euros

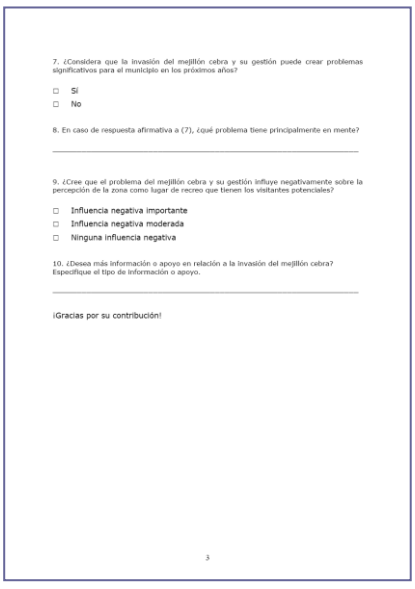
6. ¿El ayuntamiento ha recibido alguna demanda en relación a la gestión de la invasión del mejillón cebra?

☐ Sí *Especifique el tipo de demanda:*_____

_____

☐ No

2



7. ¿Considera que la invasión del mejillón cebra y su gestión puede crear problemas significativos para el municipio en los próximos años?

☐ Sí
☐ No

8. En caso de respuesta afirmativa a (7), ¿qué problema tiene principalmente en mente?

_____

9. ¿Cree que el problema del mejillón cebra y su gestión influye negativamente sobre la percepción de la zona como lugar de recreo que tienen los visitantes potenciales?

☐ Influencia negativa importante
☐ Influencia negativa moderada
☐ Ninguna influencia negativa

10. ¿Desea más información o apoyo en relación a la invasión del mejillón cebra? Especifique el tipo de información o apoyo.

_____

¡Gracias por su contribución!

3

Annex III complete specification of potential impacts caused by *D.polymorpha* in the Ter reservoirs

Tipo de impacto (daño vs control)	D/C	Tipo de impacto (dir vs indir)	Di/Ind	Efecto	Ef	Descripción efecto	Descrip-efecto2	Sector	¿Daño gestionable?	¿Cómo?	Orden de magnitud (1-decenas de miles, 2-cientos de miles, 3-millones, I-inconmensurable,)	Valor min	Valor max	No-acción _PRE	No-acción _PREALERTA	No-acción _POST-Inmediato	No-acción _POST-Persist	Mitigacion _PRE	Mitigacion _PREALERTA	Mitigacion _POST-Inmediato	Mitigacion _POST-Persist	Adaptación _PRE	Adaptación _PREALERTA	Adaptacion _POST-Inmediato	Adaptacion _POST-Persist
Daño	D	Directo de la invasión	Di	Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Recubrimiento de substratos duros (paredes, fondos) en infraestructuras para la canalización (canales, galerías)	Recubrimiento del acueducto del Pasteral a la ETAP del Ter	Ab_Hum	Si	Pre-tratamiento en la entrada al acueducto	2	20000	50000	0	0	10	8	0	0	5	3	0	0	3	0
Daño	D	Directo de la invasión	Di	Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Recubrimiento de substratos duros (paredes, fondos) en infraestructuras para la canalización (canales, galerías)	Recubrimiento de la canalización a la ETAP a la ED La Trinitat	Ab_Hum	Si	Tratamiento en la ETAP del Ter	2	20000	50000	0	0	7	5	0	0	3	1	0	0	0	0
Daño	D	Directo de la invasión	Di	Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Recubrimiento de substratos duros (paredes, fondos) en infraestructuras para la canalización (canales, galerías)	Recubrimiento del canal a la ETAP de Montoliu	Ab_Hum	Si	Instalaciones para el pre-tratamiento en el Pasteral II	3	150000	400000	0	0	10	8	0	0	10	3	0	0	3	0
Daño	D	Directo de la invasión	Di	Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Recubrimiento de substratos duros (paredes, fondos) en infraestructuras para la canalización (canales, galerías)	Recubrimiento de canales de riego	Riego	Si	Instalaciones para la filtración del caudal derivado	2	20000	50000	0	0	10	8	0	0	10	3	0	0	3	0
Daño	D	Directo de la invasión	Di	Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Recubrimiento de substratos duros (paredes, fondos) en depósitos de agua (balsas, presas, infraestructuras de decantación)	Recubrimiento de presas Sau, Susqueda, El Pasteral	Ab_Hum	No	N.A.		0	0	0	0	10	8	0	0	10	8	0	0	10	8
Daño	D	Directo de la invasión	Di	Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Recubrimiento de substratos duros (paredes, fondos) en depósitos de agua (balsas, presas, infraestructuras de decantación)	Recubrimiento de balsas de decantación en la ETAP del Ter (previas a la cloración)	Ab_Hum	Si	Intensificación de la pre-cloración	2	20000	50000	0	0	10	8	0	0	3	0	0	0	0	0
Daño	D	Directo de la invasión	Di	Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Recubrimiento de substratos duros (paredes, fondos) en depósitos de agua (balsas, presas, infraestructuras de decantación)	Recubrimiento de balsas de riego, embalse de Colomers	Riego	No?	N.A.		0	0	0	0	10	8	0	0	10	8	0	0	10	8
Daño	D	Directo de la invasión	Di	Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Recubrimiento de substratos duros (paredes, fondos) en depósitos de agua (balsas, presas, infraestructuras de decantación)	Embarcaderos en Sau	Naveg	Si	Uso de coberturas anti-adherentes	1	3000	8000	0	0	10	8	0	0	3	0	0	0	0	0
Daño	D	Directo de la invasión	Di	Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Recubrimiento de dispositivos (p.e. rejas, compuertas, arquetas, colectores, juntas, sifones, filtros, estaciones de bombeo, aspersores, circuitos de refrigeración)	Recubrimiento de instalaciones de las ETAP del Ter (ATLL)	Ab_Hum	Si	Intensificación de la pre-cloración	3	150000	400000	0	0	10	8	0	0	5	0	0	0	0	0
Daño	D	Directo de la invasión	Di	Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Recubrimiento de dispositivos (p.e. rejas, compuertas, arquetas, colectores, juntas, sifones, filtros, estaciones de bombeo, aspersores, circuitos de refrigeración)	Recubrimiento de instalaciones de las ETAP de Montoliu (AdG)	Ab_Hum	Si	Intensificación de la pre-cloración	3	150000	400000	0	0	10	8	0	0	5	0	0	0	0	0
Daño	D	Directo de la invasión	Di	Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Recubrimiento de dispositivos (p.e. rejas, compuertas, arquetas, colectores, juntas, sifones, filtros, estaciones de bombeo, aspersores, circuitos de refrigeración)	Recubrimiento de instalaciones de turbinado en las CH de Sau, Susqueda y El Pasteral	Hidro-elec	Si	Instalación de dispositivos con capacidades filtrantes, antiincrustantes, gestión de la presión del agua	3	150000	400000	0	0	10	8	0	0	5	1	0	0	0	0
Daño	D	Directo de la invasión	Di	Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Reducción del diámetro interior de conducciones de agua y tuberías, con la consiguiente disminución del flujo del agua (incremento de la fricción) (una capa de mejillones de 1-2 mm puede sponer pérdidas de carga del 5-10% en una tubería).	Recubrimiento de la conducción entre las torres de ATLL y ENDESA en Sau y Susqueda	Hidro-elec	Sí?	Interrupción de actividades de abastecimiento y producción, instalación de dispositivos con capacidades filtrates, antiincrustantes	3	150000	400000	0	0	10	8	0	0	10	0	0	0	0	0
Daño	D	Directo de la invasión	Di	Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Reducción del diámetro interior de conducciones de agua y tuberías, con la consiguiente disminución del flujo del agua (incremento de la fricción) (una capa de mejillones de 1-2 mm puede sponer pérdidas de carga del 5-10% en una tubería).	Recubrimiento de la conducción entre las torres de ENDESA y las CH	Hidro-elec	Sí?	Interrupción de actividades de producción, instalación de dispositivos con capacidades filtrates, antiincrustantes	3	150000	400000	0	0	10	8	0	0	10	0	0	0	0	0

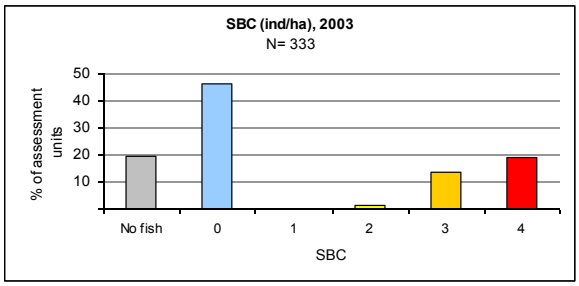
Tipo de impacto (daño vs control)	D/C	Tipo de impacto (dir vs indir)	Di/Ind	Efecto	Ef	Descripción efecto	Descrip-efecto2	Sector	¿Daño gestionable?	¿Cómo?	Orden de magnitud (1-decenas de miles, 2-cientos de miles, 3-millones, I-inconmensurable,)	Valor min	Valor max	No-acción _PRE	No-acción _PREALERTA	No-acción _POST-Inmediato	No-acción _POST-Persist	Mitigacion _PRE	Mitigacion _PREALERTA	Mitigacion _POST-Inmediato	Mitigacion _POST-Persist	Adaptación _PRE	Adaptación _PREALERTA	Adaptacion _POST-Inmediato	Adaptacion _POST-Persist
Daño	D	Directo de la invasión		Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Reducción del diámetro interior de conducciones de agua y tuberías, con la consiguiente disminución del flujo del agua (incremento de la fricción) (una capa de mejillones de 1-2 mm puede sponer pérdidas de carga del 5-10% en una tubería).	Tomas de agua en el Club Nàutic Vic-Sau y otras instalaciones	Naveg	Si	Instalación de dispositivos con capacidades filtrantes, antiincrustantes	**1**	**3000**	**8000**	0	0	10	8	0	0	10	0	0	0	0	0
Daño	D	Directo de la invasión		Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Eventual obturación de conducciones y tuberías, hidrantes	Eventual obturación de la conducción entre las torres de ATLL y Endesa	Hidro-elec	No	Es necesaria su substitución	**3**	**150000**	**400000**	0	0	10	8	0	0	0	0	0	0	0	0
Daño	D	Directo de la invasión		Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Eventual obturación de conducciones y tuberías, hidrantes	Obturación de los hidrantes y sistemas de goteo	Riego	No	Es necesaria su substitución	**2**	**20000**	**50000**	0	0	10	8	0	0	5	0	0	0	0	0
Daño	D	Directo de la invasión	Di	Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Eventual obturación de conducciones y tuberías, hidrantes	Tomas de agua en el Club Nàutic Vic-Sau y otras instalaciones	Naveg	No	Es necesaria su substitución	**1**	**3000**	**8000**	0	0	10	8	0	0	5	0	0	0	0	0
Daño	D	Directo de la invasión		Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Deterioro de equipos y materiales	Deterioro de equipos de control de calidad y dosificación	Ab_Hum	Si	Mantenimiento	**1**	**3000**	**8000**	0	0	10	8	0	0	5	0	0	0	0	0
Daño	D	Directo de la invasión		Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Deterioro de equipos y materiales	Deterioro de equipos de telecontrol (?)	Ab_Hum	Si	Mantenimiento	**1**	**3000**	**8000**	0	0	10	8	0	0	5	0	0	0	0	0
Daño	D	Directo de la invasión		Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Deterioro de equipos y materiales	Deterioro de embarcaciones; deterioro de pantalanes	Naveg	Si	Mantenimiento	**1**	**3000**	**8000**	0	0	10	8	0	0	5	0	0	0	0	0
Daño	D	Directo de la invasión	Di	Impactos en infraestructuras y equipos (disminución de vida útil; incremento de costes de mantenimiento en €)	Inf	Deterioro de equipos y materiales	Deterioro de equipos de pesca (hijos, pérdida de anzuelos)	Pesca	No	Es necesaria su substitución	**1**	**3000**	**8000**	0	0	10	8	0	0	10	3	0	0	10	1
Daño	D	Directo de la invasión	Di	Perdidas de producción en las infraestructuras afectadas (valor de la producción en unidades físicas o €; cambios en rentabilidad)	Pro	Energía eléctrica	Pérdida de producción en las CH Sau, Susqueda, El Pasteral I	Hidro-elec	Sí?	Instalación de dispositivos con capacidades filtrantes, antiincrustantes, gestión de la presión del agua (pérdida de producción durante la instalación)	**3**	**150000**	**400000**	0	0	10	8	0	0	3	0	3	0	0	0
Daño	D	Directo de la invasión	Di	Perdidas de producción en las infraestructuras afectadas (valor de la producción en unidades físicas o €; cambios en rentabilidad)	Pro	Producción agrícola	Pérdida de producción agrícola por cambios en la frecuencia de riego	Riego	No	Tal vez se devenguen subsidios compensatorios.	**2**	**20000**	**50000**	0	0	10	8	0	0	3	0	0	0	0	0
Daño	D	Directo de la invasión	Di	Perdidas de producción en las infraestructuras afectadas (valor de la producción en unidades físicas o €; cambios en rentabilidad)	Pro	Población abastecida	Población abastecida por ATLL con % reducido de fuentes propias	Ab_Hum	No	N.A.	**I**	**0**	**0**	0	0	10	8	0	0	7	3	0	0	0	0
Daño	D	Directo de la invasión	Di	Perdidas de producción en las infraestructuras afectadas (valor de la producción en unidades físicas o €; cambios en rentabilidad)	Pro	Pérdidas directas sobre el sector turístico	Pérdidas directas sobre el sector turístico	Naveg	No	N.A.	**1**	**3000**	**8000**	0	0	7	5	0	0	5	0	0	0	5	0
Daño	D	Indirecto de la gestión	Ind	Perdidas de producción en las infraestructuras afectadas (valor de la producción en unidades físicas o €; cambios en rentabilidad)	Pro	Efectos en la producción en centrales de agua fluente ante cambios en los caudales	Cambios en la producción de las CH de agua fluente	Hidro-elec	No	N.A.	**2**	**20000**	**50000**	0	0	5	3	0	?	0	0	0	?	0	0
Daño	D	Indirecto de la gestión	Ind	Perdidas de producción en las infraestructuras afectadas (valor de la producción en unidades físicas o €; cambios en rentabilidad)	Pro	Pérdidas en el sector turístico derivadas de restriccones de acceso	Disminución de actividades en el Club Nàutico Vic-Sau; actividades de la Federación Catalana de Esquí Náutico	Naveg	Si	Comunicación para la prevención	**1**	**3000**	**8000**	0	0	7	5	3	5	5	3	0	3	3	1

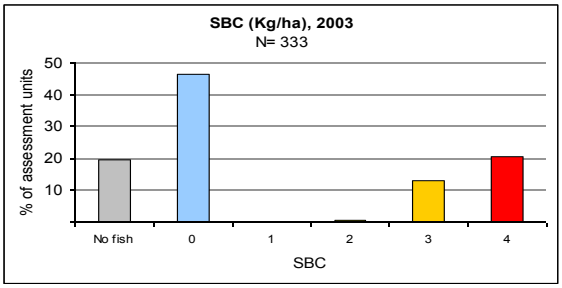
Tipo de impacto (daño vs control)	D/C	Tipo de impacto (dir vs indir)	Di/Ind	Efecto	Ef	Descripción efecto	Descrip-efecto2	Sector	¿Daño gestionable?	¿Cómo?	Orden de magnitud (1-decenas de miles, 2-cientos de miles, 3-millones, I-inconmensurable,)	Valor min	Valor max	No-acción _PRE	No-acción _PREALERTA	No-acción _POST-Inmediato	No-acción _POST-Persist	Mitigacion _PRE	Mitigacion _PREALERTA	Mitigacion _POST-Inmediato	Mitigacion _POST-Persist	Adaptación _PRE	Adaptación _PREALERTA	Adaptacion _POST-Inmediato	Adaptacion _POST-Persist
Daño	D	Indirecto de la gestión	Ind	Perdidas de producción en las infraestructuras afectadas (valor de la producción en unidades físicas o €; cambios en rentabilidad)	Pro	Pérdidas en el sector turístico derivadas de restriccones de acceso	Disminución de actividades de la Federación Catalana de Piragüismo o clubs/empresas de piragüismo	Naveg	Si	Comunicación para la prevención	1	3000	8000	0	0	7	5	3	5	5	3	0	3	3	1
Daño	D	Indirecto de la gestión	Ind	Perdidas de producción en las infraestructuras afectadas (valor de la producción en unidades físicas o €; cambios en rentabilidad)	Pro	Pérdidas en el sector turístico derivadas de restriccones de acceso	Disminución de ingresos asociados a licencias y concursos de pesca en los tres embalses	Pesca	Si	Comunicación para la prevención	1	3000	8000	0	0	7	5	0	5	5	3	0	3	3	1
Daño	D	Directo de la invasión	Di	Daño en los servicios ambientales asociados a la la calidad del medio (cualitativo)	SA	Percepción de pérdida de calidad del medio	Cambios en la fauna piscícola de interés recreativo o comercial	Pesca	Si	Comunicación	I	0	0	0	0	10	8	0	0	10	8	0	0	10	8
Daño	D	Directo de la invasión	Di	Daño en los servicios ambientales asociados a la la calidad del medio (cualitativo)	SA	Disponibilidad de agua (necesidad de fuentes alternativas de abastecimiento)	Necesidad de fuentes alternativas de abastecimiento de agua potable; sobreuso de fuentes alternativas	Ab_Hum	Si	Búsqueda de fuentes alternativas	3	150000	400000	0	0	10	8	0	0	7	3	0	0	0	0
Daño	D	Directo de la invasión	Di	Daño en los servicios ambientales asociados a la la calidad del medio (cualitativo)	SA	Disponibilidad de agua (necesidad de fuentes alternativas de abastecimiento)	Necesidad de fuentes alternativas de agua de riego; sobreuso de fuentes alternativas	Riego	Si	Búsqueda de fuentes alternativas	3	150000	400000	0	0	10	8	0	0	7	3	0	0	0	0
Daño	D	Indirecto de la gestión	Ind	Daño en los servicios ambientales asociados a la la calidad del medio (cualitativo)	SA	Impactos en la calidad del agua por tratamientos.	Impactos en la calidad del agua por tratamientos.	Ab_Hum	Si	Tratamientos de depuración	2	20000	50000	0	0	0	0	0	0	3	5	0	3	5	5
Daño	D	Indirecto de la gestión	Ind	Daño en los servicios ambientales asociados a la la calidad del medio (cualitativo)	SA	Percepción de pérdida del valor recreativo/ estético de la masa de agua por restricciones de acceso	Percepción negativa del área por eventual prohibición o confinameinto de la navegación en Sau (impedimento para navegar en otras áreas); eventual confinamiento de las embarcaciones a remo	Naveg	Si	Comunicación para la prevención	I	0	0	0	0	10	8	0	3	5	5	0	0	3	5
Daño	D	Indirecto de la gestión	Ind	Daño en los servicios ambientales asociados a la la calidad del medio (cualitativo)	SA	Percepción de pérdida del valor recreativo/ estético de la masa de agua por restricciones de acceso	Percepción negativa del área por la eventual prohibición de la pesca	Naveg	Si	Comunicación para la prevención	I	0	0	0	0	0	0	0	5	5	5	0	3	3	3
Control	C	Directo de la invasión	Di	Instalación de equipos, dispositivos y tratamientos para evitar la entrada, establecimiento e impactos del mejillón cebra:	Eq	Adaptación de infraestructuras	Reposición de equipos con nuevas propiedades en las 3 CH	Hidro-elec			3	150000	400000	0	0	0	0	0	0	10	0	10	0	0	0
Control	C	Indirecto de la gestión	Ind	Instalación de equipos, dispositivos y tratamientos para evitar la entrada, establecimiento e impactos del mejillón cebra:	Eq	Adaptación de infraestructuras	Adaptación de las infraestructuras en la captación de El Pasteral (Filtración, mejora de la pre-cloración)	Ab_Hum			3	150000	400000	0	0	0	0	0	0	10	0	10	0	0	0
Control	C	Indirecto de la gestión	Ind	Instalación de equipos, dispositivos y tratamientos para evitar la entrada, establecimiento e impactos del mejillón cebra:	Eq	Adaptación de infraestructuras	Instalaciones para el pre-tratamiento en el Pasteral II	Ab_Hum			3	150000	400000	0	0	0	0	0	0	10	0	10	0	0	0
Control		Indirecto de la gestión	Ind	Instalación de equipos, dispositivos y tratamientos para evitar la entrada, establecimiento e impactos del mejillón cebra:	Eq	Adaptación de infraestructuras	Filtros en sistemas de riego	Riego			3	150000	400000	0	0	0	0	0	0	10	0	10	0	0	0
Control	C	Indirecto de la gestión	Ind	Instalación de equipos, dispositivos y tratamientos para evitar la entrada, establecimiento e impactos del mejillón cebra:	Eq	Recubrimientos (p.e. pinturas) o materiales anti-incrustantes	Protección de rejas	Ab_Hum			2	20000	50000	0	0	0	0	0	0	10	0	10	0	0	0
Control	C	Indirecto de la gestión	Ind	Instalación de equipos, dispositivos y tratamientos para evitar la entrada, establecimiento e impactos del mejillón cebra:	Eq	Recubrimientos (p.e. pinturas) o materiales anti-incrustantes	Embarcaciones	Naveg			1	3000	8000	0	0	0	0	0	0	10	0	10	0	0	0
Control	C	Indirecto de la gestión	Ind	Instalación de equipos, dispositivos y tratamientos para evitar la entrada, establecimiento e impactos del mejillón cebra:	Eq	Equipos de desinfección	Equipos desinfección	Naveg			1	3000	8000	0	0	0	0	10	0	0	0	0	0	5	0
Control	C	Indirecto de la gestión	Ind	Instalación de equipos, dispositivos y tratamientos para evitar la entrada, establecimiento e impactos del mejillón cebra:	Eq	Cambio en los tratamientos del agua	Pre-cloración de agua para abastecimiento en Pasteral	Ab_Hum			2	20000	50000	0	0	0	0	0	0	10	8	0	5	10	8
Control	C	Indirecto de la gestión	Ind	Instalación de equipos, dispositivos y tratamientos para evitar la entrada, establecimiento e impactos del mejillón cebra:	Eq	Cambio en los tratamientos del agua	Pre-cloración en la derivación del Pasteral II	Ab_Hum			2	20000	50000	0	0	0	0	0	0	10	8	0	5	10	8

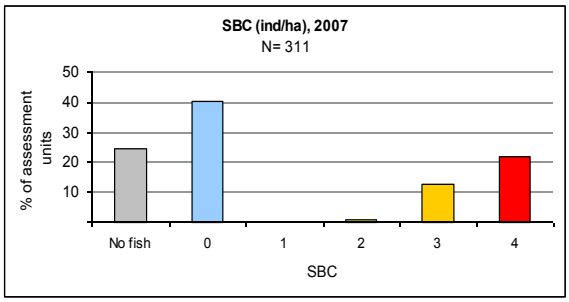
Tipo de impacto (daño vs control)	D/C	Tipo de impacto (dir vs indir)	Di/Ind	Efecto	Ef	Descripción efecto	Descrip-efecto2	Sector	¿Daño gestionable?	¿Cómo?	Orden de magnitud (1-decenas de miles, 2-cientos de miles, 3-millones, I-inconmensurable,)	Valor min	Valor max	No-acción _PRE	No-acción _PREALERTA	No-acción _POST-Inmediato	No-acción _POST-Persist	Mitigacion _PRE	Mitigacion _PREALERTA	Mitigacion _POST-Inmediato	Mitigacion _POST-Persist	Adaptación _PRE	Adaptación _PREALERTA	Adaptacion _POST-Inmediato	Adaptacion _POST-Persist
Control	C	Indirecto de la gestión	Ind	Instalación de equipos, dispositivos y tratamientos para evitar la entrada, establecimiento e impactos del mejillón cebra:	Eq	Cambio en los tratamientos del agua	Incremento de la pre-cloración y cloración en la ETAP del Ter; ETAP de Montoliu	Ab_Hum			**2**	**20000**	**50000**	0	0	0	0	0	0	10	8	0	5	10	8
Control	C	Indirecto de la gestión	Ind	Instalación de equipos, dispositivos y tratamientos para evitar la entrada, establecimiento e impactos del mejillón cebra:	Eq	Cambio en los tratamientos del agua	Tratamientos en sistemas de riego	Riego			**2**	**20000**	**50000**	0	0	0	0	0	0	10	8	0	5	10	8
Control	C	Directo de la invasión	Di	Costes adicionales de administración y gestión (en €)	Ge	Costos de monitoreo de la invasión	Costes de monitoreo de larvas	Administr			**1**	**3000**	**8000**	0	0	0	0	10	10	5	3	5	7	3	1
Control	C	Directo de la invasión	Di	Costes adicionales de administración y gestión (en €)	Ge	Costos de monitoreo de la invasión	Costes de monitoreo de adultos	Administr			**1**	**3000**	**8000**	0	0	0	0	10	10	5	3	0	10	3	1
Control	C	Directo de la invasión	Di	Costes adicionales de administración y gestión (en €)	Ge	Costes de investigación	Costes de investigación	Administr			**2**	**20000**	**50000**	0	0	0	0	10	10	5	3	5	5	5	3
Control	C	Directo de la invasión	Di	Costes adicionales de administración y gestión (en €)	Ge	Costes de comunicación	Costes de comunicación	Administr			**1**	**3000**	**8000**	0	0	0	0	10	10	10	8	5	10	10	5
Control	C	Indirecto de la gestión	Ind	Costes adicionales de administración y gestión (en €)	Ge	Costos de gestión por maniobras de cambio de caudal (desguace, cierre de compuertas)	Costes de gestión de maniobras en las presas	Hidro-elec			**1**	**3000**	**8000**	0	0	0	0	0	7	0	0	0	5	0	0
Control			Ind		Ge	Costes de gestión en los riegos	Costes de gestión en los riegos	Riego			**1**	**3000**	**8000**	0	0	0	0	0	0	3	5	0	0	3	5
Control	C	Indirecto de la gestión	Ind	Costes adicionales de administración y gestión (en €)	Ge	Costos adicionales de certificación de limpieza de embarcaciones	Costos adicionales de certificación de limpieza de embarcaciones	Administr			**1**	**3000**	**8000**	0	0	0	0	10	10	10	8	0	0	5	3
Control		Indirecto de la gestión		Costes adicionales de administración y gestión (en €)	Ge	Costes de control y vigilancia	Costes de control y vigilancia	Administr			**2**	**20000**	**50000**	0	0	0	0	10	10	10	8	0	0	5	3
Control	C	Indirecto de la gestión	Ind	Costes adicionales de administración y gestión (en €)	Ge	Gastos encaminados a la mitigación, subvenciones para la instalación de equipos	Gastos encaminados a la mitigación, subvenciones para la instalación de equipos	Administr			**2**	**20000**	**50000**	0	0	0	0	5	5	10	0	10	10	0	0
Control	C	Indirecto de la gestión	Ind	Costes adicionales de administración y gestión (en €)	Ge	Costes de gestión (p.e comunicación para la mitigación de efectos indicrectos, convenios entre administración)	Coste del establecimiento de convenios y protocolos dentro de laadministración	Administr			**1**	**3000**	**8000**	0	0	0	0	10	10	5	3	5	5	0	0
Control	C	Indirecto de la gestión	Ind	Costes adicionales de administración y gestión (en €)	Ge	Costes de gestión (p.e comunicación para la mitigación de efectos indicrectos, convenios entre administración)	Coste del establecimiento de convenios y protocolos con la administración	Naveg			**1**	**3000**	**8000**	0	0	0	0	10	10	5	3	5	5	0	0
Control	C	Indirecto de la gestión	Ind	Costes adicionales de administración y gestión (en €)	Ge	Costes de gestión (p.e comunicación para la mitigación de efectos indicrectos, convenios entre administración)	Coste del establecimiento de convenios y protocolos con la administración	Pesca			**1**	**3000**	**8000**	0	0	0	0	10	10	5	3	5	5	0	0

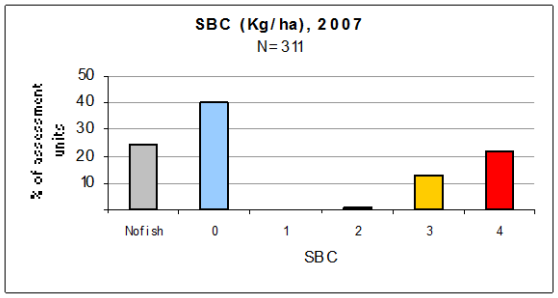
Annex IV Results of the determination of the Site-specific contamination level, using fish, for the water bodies in Catalonia (2002-2003 and 2007-2008), for different indicators of AS abundance (density [ind/ha] and biomass [kg/ha])

a) Results for all assessment units

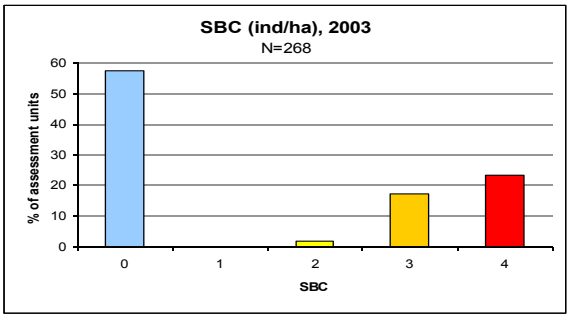


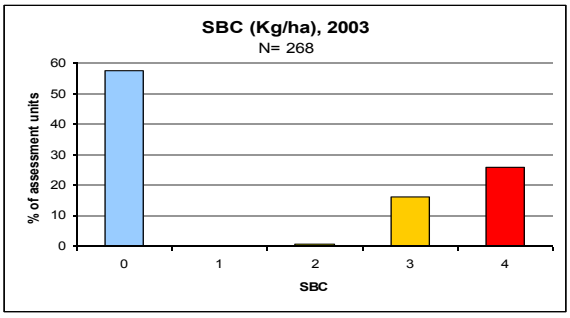


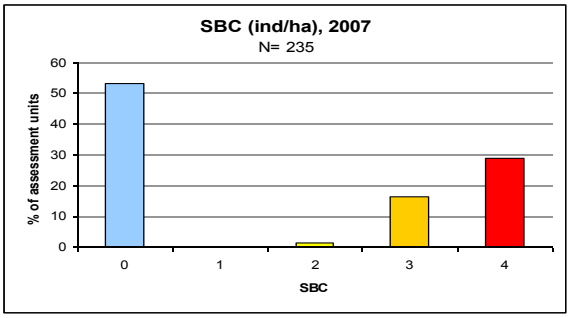


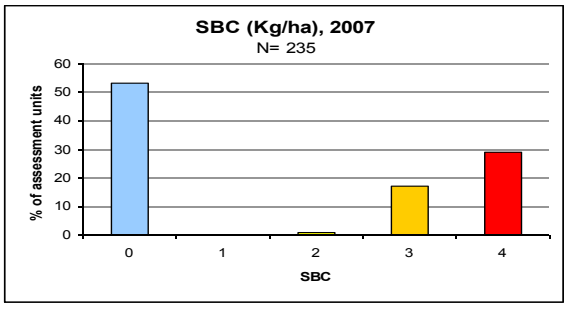


b) Results for assessment units with fish fauna



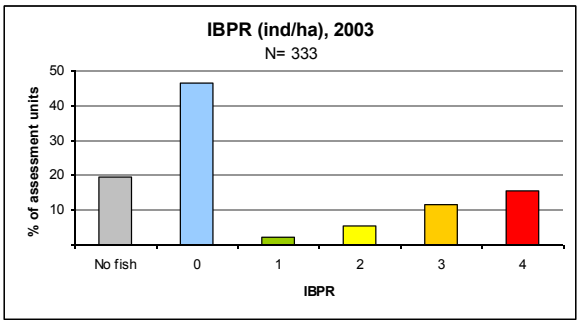


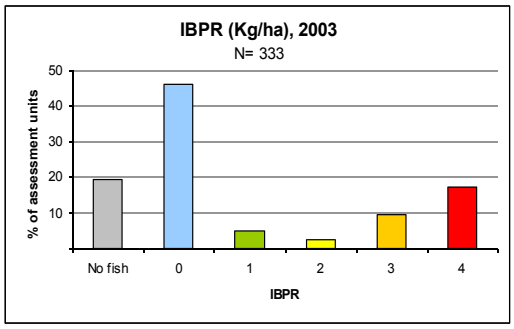


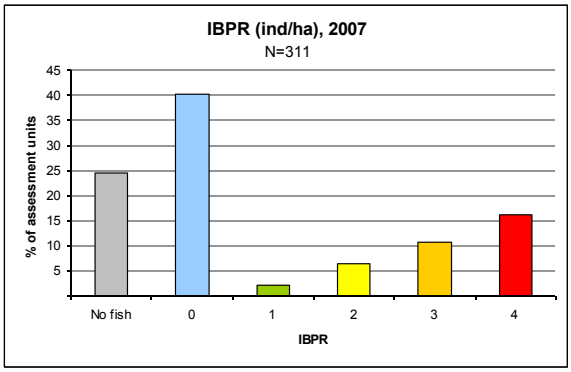


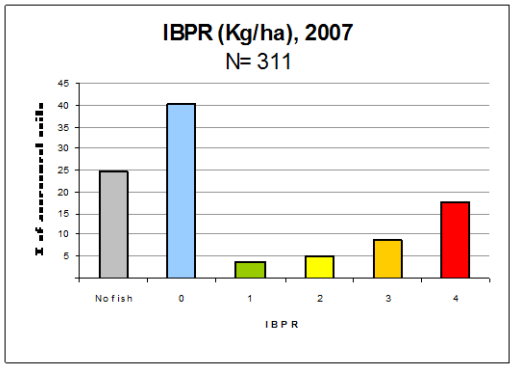
Annex V Results of the determination of Biopolution Risk Index, using fish, for the water bodies in Catalonia (2002-2003 and 2007-2008), for different indicators of AS abundance (Ind/ha and kg/ha)

a) Results for all assessment units

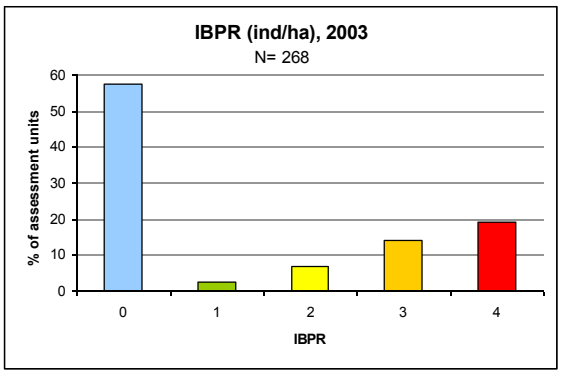


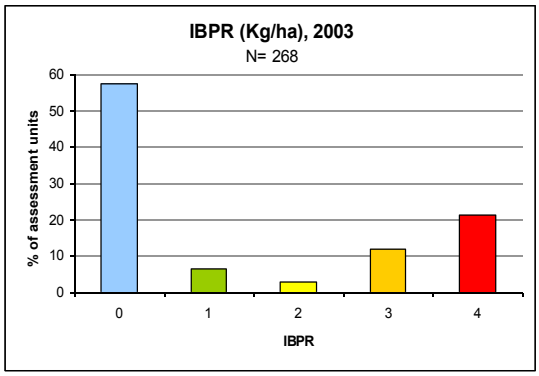


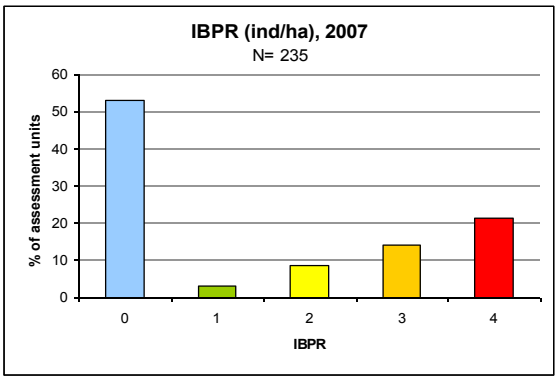


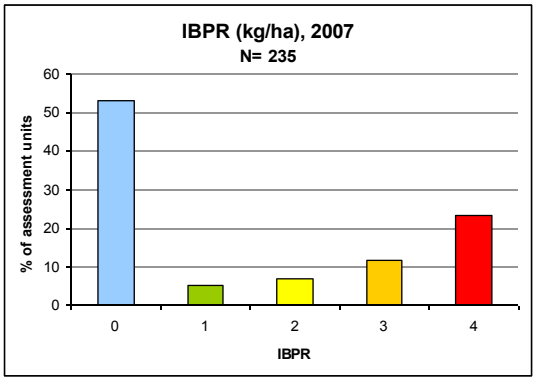


b) Results for assessment units with fish fauna









Annex VI BC&BP levels and pressures, results of the correlation analysis

Source: Own elaboration

Data on BP& BC in 2003			SBCindha	SBCkgha	IBPRindha	IBPRkgha	RIAP
Kendall's tau_b	SBCindha	Correlation Coefficient	1.000	.924**	.891**	.836**	.215**
		Sig. (2-tailed)	.	.000	.000	.000	.000
		N	246	246	246	246	246
	SBCkgha	Correlation Coefficient	.924**	1.000	.899**	.902**	.240**
		Sig. (2-tailed)	.000	.	.000	.000	.000
		N	246	246	246	246	246
	IBPRindha	Correlation Coefficient	.891**	.899**	1.000	.907**	.243**
		Sig. (2-tailed)	.000	.000	.	.000	.000
		N	246	246	246	246	246
	IBPRkgha	Correlation Coefficient	.836**	.902**	.907**	1.000	.240**
		Sig. (2-tailed)	.000	.000	.000	.	.000
		N	246	246	246	246	246
	RIAP	Correlation Coefficient	.215**	.240**	.243**	.240**	1.000
		Sig. (2-tailed)	.000	.000	.000	.000	.
		N	246	246	246	246	295
Spearman's rho	SBCindha	Correlation Coefficient	1.000	.965**	.954**	.927**	.274**
		Sig. (2-tailed)	.	.000	.000	.000	.000
		N	246	246	246	246	246
	SBCkgha	Correlation Coefficient	.965**	1.000	.957**	.959**	.305**
		Sig. (2-tailed)	.000	.	.000	.000	.000
		N	246	246	246	246	246
	IBPRindha	Correlation Coefficient	.954**	.957**	1.000	.964**	.315**
		Sig. (2-tailed)	.000	.000	.	.000	.000
		N	246	246	246	246	246
	IBPRkgha	Correlation Coefficient	.927**	.959**	.964**	1.000	.310**
		Sig. (2-tailed)	.000	.000	.000	.	.000
		N	246	246	246	246	246
	RIAP	Correlation Coefficient	.274**	.305**	.315**	.310**	1.000
		Sig. (2-tailed)	.000	.000	.000	.000	.
		N	246	246	246	246	295

**. Correlation is significant at the 0.01 level (2-tailed).

Data on BP& BC in 2007			SBCindha	SBCkgha	IBPRindha	IBPRkgha	RIAP
Kendall's tau_b	SBCindha	Correlation Coefficient	1.000	.967**	.886**	.877**	.219**
		Sig. (2-tailed)	.	.000	.000	.000	.000
		N	235	235	235	235	235
	SBCkgha	Correlation Coefficient	.967**	1.000	.894**	.900**	.208**
		Sig. (2-tailed)	.000	.	.000	.000	.000
		N	235	235	235	235	235
	IBPRindha	Correlation Coefficient	.886**	.894**	1.000	.959**	.224**
		Sig. (2-tailed)	.000	.000	.	.000	.000
		N	235	235	235	235	235
	IBPRkgha	Correlation Coefficient	.877**	.900**	.959**	1.000	.239**
		Sig. (2-tailed)	.000	.000	.000	.	.000
		N	235	235	235	235	235
	RIAP	Correlation Coefficient	.219**	.208**	.224**	.239**	1.000
		Sig. (2-tailed)	.000	.000	.000	.000	.
		N	235	235	235	235	311
Spearman's rho	SBCindha	Correlation Coefficient	1.000	.983**	.949**	.944**	.282**
		Sig. (2-tailed)	.	.000	.000	.000	.000
		N	235	235	235	235	235
	SBCkgha	Correlation Coefficient	.983**	1.000	.953**	.956**	.271**
		Sig. (2-tailed)	.000	.	.000	.000	.000
		N	235	235	235	235	235
	IBPRindha	Correlation Coefficient	.949**	.953**	1.000	.985**	.296**
		Sig. (2-tailed)	.000	.000	.	.000	.000
		N	235	235	235	235	235
	IBPRkgha	Correlation Coefficient	.944**	.956**	.985**	1.000	.313**
		Sig. (2-tailed)	.000	.000	.000	.	.000
		N	235	235	235	235	235
	RIAP	Correlation Coefficient	.282**	.271**	.296**	.313**	1.000
		Sig. (2-tailed)	.000	.000	.000	.000	.
		N	235	235	235	235	311

**. Correlation is significant at the 0.01 level (2-tailed).

Annex VII Templates for the scenario workshop (2005)

Source: Rodríguez-Labajos (2006)

Objetivos

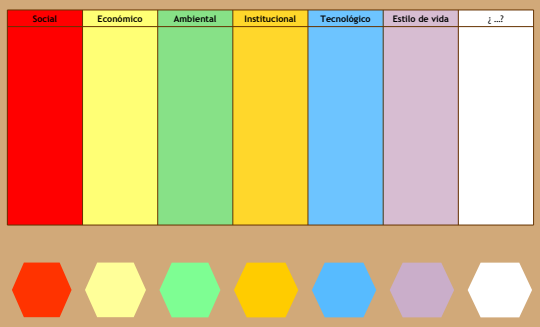
A partir de la información disponible y percepción de los actores:

- Identificar y jerarquizar los factores que inciden en el establecimiento, impactos y respuesta a las invasiones biológicas (mejillón cebra y siluro) en los pantanos de Mequinenza, Riba-roja y Flix.
- Compartir puntos de vista en relación a los criterios relevantes a la hora de definir una respuesta a la invasión, reconociendo las implicaciones de las respectivas propuestas.
- Diseñar escenarios de gestión incorporando las diversas visiones de cada actor.

Actividad 1.
Identificación de factores relevantes en los procesos de invasión del mejillón cebra y el siluro

En tres grupos, los participantes generarán una lista de posibles factores que inciden en el establecimiento, impactos y respuesta a estas invasiones.

30 - 45 minutos



Actividad 2.
Jerarquía de factores

A partir de la lista anterior y utilizando fichas, los tres grupos clasificarán de manera preliminar los factores en función de si resultan más o menos

RELEVANTES INCIERTOS

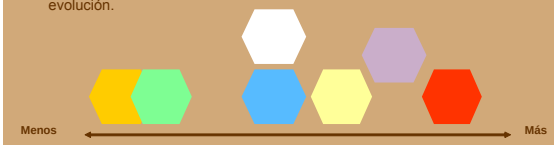
45 min - 1 hora

RELEVANTE

Es importante para explicar porqué las cosas se han dado de una determinada manera.

INCIERTO

Su evolución en el futuro no es fácil de predecir. Lo que pase con este factor no está grabado en piedra. Existe flexibilidad para intervenir en su evolución.



Mediante esta actividad se prepara la siguiente, en la que la clasificación de los factores se discutirá en plenaria.

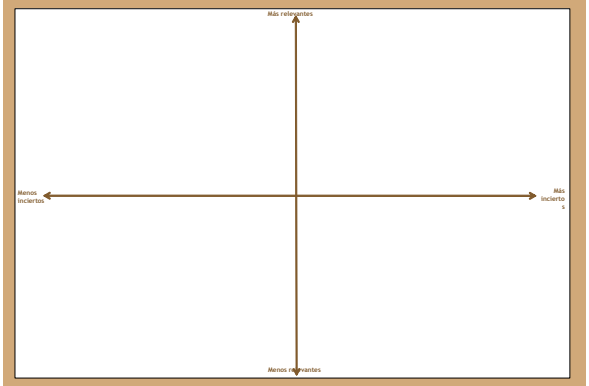
Actividad 3.
Organización de la jerarquía de factores e identificación de temas subyacentes clave

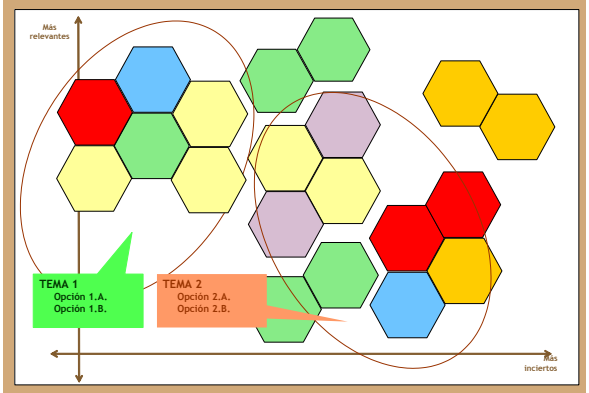
En plenaria, los resultados de los tres grupos permitirán acordar una jerarquía de factores que integre la percepción sobre su relevancia e incertidumbre.

1 h 30 min - 2 h

A partir de esta jerarquía, la plenaria decidirá los temas subyacentes clave que deben están en la base de los escenarios a desarrollar.

30 min - 1 h





Actividad 4.
Generación de escenarios

A partir de la combinación de los diferentes temas clave, se generarán cuatro escenarios básicos.

En cuatro grupos, los participantes dotarán de contenidos a cada escenario.

a. Designación de los escenarios
b. Identificación de criterios / indicadores
c. Definición de preguntas clave para el desarrollo de narrativas
d. Desarrollo de narrativas

2 h

¿ De dónde surgen los escenarios ?

		Legislación/Administración	
		Intervención integrada 2.A	'Statu quo' 2.B
Gestión de los usos del agua	Ambiental 1.A	ESCENARIO I	ESCENARIO II
	Ocio/ Negocio 1.B	ESCENARIO III	ESCENARIO IV