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## River Continuity Restoration and Diadromous Fishes: Much More than an Ecological Issue

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# 1 **River Continuity Restoration and diadromous fishes: much more than an** 2 **ecological issue**

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12

## 13 **Abstract**

14 Ecosystem fragmentation is a serious threat to biodiversity and one of the main challenges in  
15 ecosystem restoration. River Continuity Restoration (RCR) has often targeted diadromous fishes, a  
16 group of species supporting strong cultural and economic values and especially sensitive to river  
17 fragmentation. Yet it has frequently produced mixed results and diadromous fishes remain at very  
18 low levels of abundance. Against this background, this paper presents the main challenges for  
19 defining, evaluating and achieving effective RCR. We first identify challenges specific to  
20 disciplines. In ecology, there is a need to develop quantitative and mechanistic models to support  
21 decision making, accounting for both direct and indirect impacts of river obstacles and working at  
22 the river catchment scale. In a context of dwindling abundances and reduced market value, cultural  
23 services provided by diadromous fishes are becoming increasingly prominent. Methods for carrying  
24 out economic quantification of non-market values of diadromous fishes become ever more urgent.  
25 Given current challenges for rivers to meet all needs sustainably, conflicts arise over the legitimate

26 use of water resources for human purposes. Concepts and methods from political science and  
27 geography are needed to develop understandings on how the political work of public authorities and  
28 stakeholders can influence the legitimacy of restoration projects. Finally, the most exciting  
29 challenge is to combine disciplinary outcomes to achieve a multidisciplinary approach to RCR.  
30 Accordingly, the co-construction of intermediary objects and diagrams of flows of knowledge  
31 among disciplines can be first steps towards new frameworks supporting restoration design and  
32 planning.

33

34 Keywords: diadromous fishes; river fragmentation; ecosystem goods and services; territory; policy;  
35 multidisciplinary approach

36

## 37 **1 Context: an intensification of efforts towards RCR and diadromous fishes'** 38 **protection**

### 39 **1.1 Ecosystem restoration and the specific case of River Continuity Restoration in the light** 40 **of river fragmentation**

41 At the beginning of the 21st century, the Millennium Assessment pointed out that despite a global  
42 increase in human welfare, ecosystem modifications due to anthropogenic activities were  
43 threatening ecosystems' ability to sustainably provide important goods and services, especially for  
44 future generations (Millennium Ecosystem Assessment 2005). This alarming situation applied to  
45 both terrestrial and aquatic ecosystems. For example, rivers provide a multitude of goods and  
46 services to society (Postel and Richter 2003; Wolanski et al. 2011; Elliott and Whitfield 2011) that  
47 are potentially threatened due to many factors including: dam and dyke construction; pollution;  
48 water extraction for human consumption or irrigation; drying out of lateral wetlands;  
49 hydromorphological modifications; fishing; and land use in the floodplain (Elliott and Hemingway  
50 2002; Postel and Richter 2003; Basset et al. 2013). In this article, using diadromous fishes and  
51 River Continuity Restoration (RCR, i.e. restoring free movement of fishes and/or physical and

52 ecological components continuum) in France as an example, we will illustrate the need for an  
53 interdisciplinary approach to conceptualize, achieve and evaluate effective ecosystem restoration for  
54 diadromous fishes and identify key challenges raised by such an approach.

55 Indeed, ecological fragmentation disrupting ecological connectivity has been defined as one of the  
56 major challenges in ecosystem restoration and conservation (Tischendorf and Fahrig 2000a, b;  
57 Kondolf et al. 2006; Crook et al. 2009; Humphries and Winemiller 2009; Sutherland et al. 2013).  
58 The notion of “ecological connectivity/continuity” or more generally “landscape connectivity”  
59 comes from landscape ecology (Forman and Godron 1986). Ecological connectivity refers to the  
60 possibility of genes, individuals, energy or matter to move from an ecological patch (defined as a  
61 homogeneous unit of environment) to another because of the landscape structure (Ward and  
62 Stanford 1995; Ward et al. 1999). Ecosystem fragmentation can arise from natural or anthropogenic  
63 obstacles that impair animal movements. Dams or mill-weirs are among the most typical examples  
64 of obstacles in the case of river connectivity. Such obstacles can either be transversal (weirs,  
65 dams...), i.e. affecting movements upstream / downstream, or lateral (dykes), i.e. impacting  
66 movements between a river and its floodplain.

67 In aquatic ecosystems, river fragmentation has significant impacts on fish assemblages’  
68 composition, abundance and spatial distribution (Matthews and Robison 1998; Poulet 2007; Araújo  
69 et al. 2009; Nislow et al. 2011; Perkin and Gido 2012; Gardner et al. 2013), and on the resilience of  
70 populations because of genetic isolation (Jager et al. 1999, 2001; Fagan 2002; Horreo et al. 2011;  
71 Webb and Padgham 2013). However, river fragmentation has other kinds of impacts on ecosystem  
72 functioning such as habitat alteration or modification, variation of water table recharge, reduced  
73 denitrification, modification of flood regimes or changes in the interdependency between the river  
74 and its floodplain (Nilsson and Berggren 2000; Gergel et al. 2005). RCR aims at enhancing river  
75 ecological functioning by favouring a longitudinal biotic and physical continuum (Vannote et al.  
76 1980), as well as a lateral continuity between rivers and their floodplains (Amoros and Roux 1988)  
77 and also a vertical continuity between the water column and river sediment.

78 In view of this, initiatives to restore river continuity have flourished at international, national and  
79 regional scales. In Europe for example, the Water Framework Directive (WFD - 2000/60/CE)  
80 established new requirements in order to achieve good ecological status of water bodies in each  
81 European Union (EU) Member State and specifically mentioned river continuity as a key  
82 component of good ecological status. In France, the WFD resulted, inter alia, in the implementation  
83 of a water and aquatic environments' law (Loi n° 2006-1772 30 December, 2006 sur l'eau et les  
84 milieux aquatiques: LEMA) which implements a new river classification system to prioritize rivers  
85 in which continuity must be restored or protected. Recently, the “Blue and Green Infrastructure”  
86 policies implemented in light of both the French environmental programme 2008 (Grenelle de  
87 l'Environnement), and the EU's “Green Infrastructure Strategy” (COM(2013) 249 final), detail  
88 specific projects on terrestrial and aquatic continuity preservation and restoration, based on a  
89 network of classified patches of biodiversity interconnected along ecological corridors (Forman and  
90 Godron 1986).

91

## 92 **1.2 Diadromous fishes: high value species impacted by river fragmentation**

93 Diadromous fishes refer to approximately 250 species that share their life cycles between  
94 freshwater and marine habitats (Myers 1949; McDowall 1997). Many of them are iconic food and  
95 sport fishes, and have been intensively studied (Bloom and Lovejoy 2014). As an illustration of the  
96 importance of diadromous fishes, in France their landings accounted for 75% of total income of the  
97 commercial inland fishery at the end of the 20<sup>th</sup> century (Champion 1999; Boisneau and  
98 Mennesson-Boisneau 2001). Historically, *Acipenser sturio* fishing and caviar production used to be  
99 an important industry at the beginning of the 20<sup>th</sup> century (Castelnaud 2011). Later, European eel  
100 (*Anguilla anguilla*) was the most important species landed in value in the Bay of Biscay  
101 (Castelnaud 2000) in the early 2000s, especially because of the high market value of glass eels  
102 (Ringuet et al. 2002; Briand et al. 2007). Other species have a more limited value when compared to  
103 marine species, however they may be of regional importance. Allis shad (*Alosa alosa*) and to a

104 minor extent twait shads (*Alosa fallax*) are harvested in continental waters throughout their range  
105 though their market value has decreased because of abundance decline (Bagliniere et al. 2003).  
106 Lampreys (*Petromyzon marinus* and *Lampetra fluviatilis*) have a long history of commercial fishing  
107 because of their gastronomic delicacy (Kelly and King 2001). Atlantic salmon (*Salmo salar*) is  
108 targeted by a high profile recreational fishery, as all over its distribution area (Verspoor et al. 2007).  
109 This question of RCR is crucial for diadromous fish restoration. Most freshwater fishes carry out  
110 seasonal migrations (Brönmark et al. 2014), however, diadromous fishes must carry out migrations  
111 between fresh and marine waters to complete their life cycle (Myers 1949; McDowall 1988). There  
112 are three types of diadromous species (McDowall 1988). Anadromous species, such as many  
113 salmon, spend most of their growth phase at sea and reproduce in freshwater. On the other hand,  
114 catadromous species, such as the European eel, reproduce in marine waters and spend most of their  
115 growth phase in continental waters. Finally, amphidromous fishes reproduce in freshwater and share  
116 their growth phase between freshwater and marine waters (McDowall 1988). This remarkable life-  
117 history behaviour has evolved in many fish groups (Feutry et al. 2013) but many of these species, as  
118 more generally most migratory species from the animal kingdom (Sanderson et al. 2006; Berger et  
119 al. 2008; Wilcove and Wikelski 2008), are now in decline all over the world (McDowall 1999;  
120 Limburg and Waldman 2009). Many factors explain this decline, however river fragmentation due  
121 to dams, weirs, flood gates or other physical obstacles has been considered to be one of the main  
122 causes both of their decline (Limburg and Waldman 2009). By impairing free-movements from  
123 reproduction to growth habitats, obstacles can interrupt fishes life-cycle and have led to their  
124 extinction (*Salmo salar* in the Rhine River, in the Seine River or in the Garonne River for example),  
125 or indeed of their confinement in restricted areas of rivers basins (*Salmo salar* in Loire River, *Alosa*  
126 *alosa* in the Rhône River and the Garonne River) (Porcher and Travade 1992; Kondolf 1997;  
127 Coutant and Whitney 2000; Larinier 2001; Fukushima et al. 2007; Limburg and Waldman 2009;  
128 Lawrence et al. 2016). Because of their high economic and cultural values and other goods and  
129 services they support (Dams 1987; Citerne 1998, 2004; Limburg and Waldman 2009), RCR has

130 often focused on diadromous fishes. For example, most WFD fish indicators include a metric based  
131 on diadromous species (Breine et al. 2007; Coates et al. 2007; Pont et al. 2009; Delpech et al. 2010;  
132 Scholle and Schuchardt 2012) aiming at assessing river continuity, one of the component of  
133 ecological quality defined in this directive. Similarly, in France, river classification and the French  
134 Blue Infrastructure were mostly based on species of interest including many diadromous fishes.  
135 Moreover, many types of fishways, the most common mitigation measure to river fragmentation,  
136 have been specifically designed for diadromous species, especially salmonids (Larinier 2001;  
137 Noonan et al. 2012). The predominance of diadromous fishes in RCR suggest that some diadromous  
138 fishes are good candidates to be considered as “cultural keystone species” as defined by Garibaldi  
139 and Turner (2004), i.e. “culturally salient species that shape in a major way the cultural identity of a  
140 people”. However, RCR for diadromous fishes implies modifications of barriers, or even obstacles  
141 removals, while many obstacles also carry strong cultural values and provide many services (Fox et  
142 al. 2016). The potential reshaping of ecosystems goods and services provided by diadromous fishes,  
143 from market to non-market values, because of their decline and the emerging conflicts with  
144 ecosystem goods and services provided by obstacles, are central questions for the future of RCR for  
145 diadromous fishes.

146

147

## 148 **2 RCR for diadromous fishes: inconsistent results and upcoming challenges**

### 149 **2.1 Restoration of aquatic ecosystems and RCR for diadromous fishes: inconsistent results**

150 Though aquatic ecosystem restoration has a long history in Europe and all over the world (Palmer et  
151 al. 2014; Morandi et al. 2014), its impacts are often considered mixed (Palmer et al. 2010; Suding  
152 2011; Jähnig et al. 2011; Palmer et al. 2014). Several reasons have been proposed to explain these  
153 disappointing results. The first reason is the complexity of aquatic ecosystems functioning based on  
154 biological, physical and chemical processes and anthropogenic pressures that work at different  
155 temporal and spatial scales. This complexity impairs our ability to understand ecosystem

156 functioning and challenges our ability to develop appropriate tools to predict and validate the effects  
157 of restoration actions (Arthington et al. 2010; Olden et al. 2014; Lamouroux et al. 2015).  
158 Additionally, it makes it difficult to implement restoration actions at appropriate temporal and  
159 spatial scales (Palmer et al. 2010; Hermoso et al. 2012; Perring et al. 2015). Over and above this  
160 complexity, the mixed results of aquatic ecosystem restoration may also be the result of a poor  
161 linkage between science and management. This results in gaps in scientific knowledge that would  
162 be crucial for managers, in scientific results that are of poor practical use for managers, and  
163 conversely, in the under-use of scientific results by managers (Cabin 2007; Palmer 2008; Suding  
164 2011).

165 Another barrier to effective restoration is the lack of consideration of the societal context in which  
166 restoration programs take place (Hermoso et al. 2012; Wortley et al. 2013). In a review, Wortley *et*  
167 *al.* (2013) highlighted that socio-economic dimensions had been considered in only a few  
168 restoration programs even though Pahl-Wostl et al. (2013) had underlined that the main barriers to  
169 effective restoration often arise from the socio-economic context because of diverging and  
170 fluctuating objectives among stakeholders (Barthélémy and Souchon 2009; Jørgensen and Renöfält  
171 2013; Perring et al. 2015) and unshared spatial and temporal scales at which they consider  
172 restoration (Hermoso et al. 2012).

173 Despite long-terms efforts to restore diadromous fishes (the first laws were adopted in the 1700s for  
174 salmon: (Brown et al. 2013)), these restoration programs have also had mixed success (Lichatowich  
175 and Lichatowich 2001; Lichatowich and Williams 2009). A famous example is the failure of the  
176 recovery program of Pacific salmon in the Columbia river, which has been called the world's largest  
177 attempt at ecosystem restoration, but resulted in a failure (Lichatowich and Williams 2009).

178 Regulation on fishing activities, construction of fishways and restocking from hatcheries are among  
179 the main measures implemented to conserve and restore diadromous fishes. Regarding more  
180 specifically RCR for diadromous fishes, the construction of fishways to mitigate the impact of  
181 obstacles to migration is the most common mitigation measure. But, fishways can be considered as



182 half-way measures (Brown et al. 2013), i.e. measures that do not prevent or solve the problem but  
183 only mitigate the symptoms, and often have limited efficiency (Noonan et al. 2012). Obstacles  
184 removal appears to be much more ecologically efficient (Garcia De Leaniz 2008; Hitt et al. 2012)  
185 and is more and more perceived as a critical tool in river restoration in general and migratory fishes  
186 in particular (Doyle et al. 2003; Magilligan et al. 2017). However, it raises many more socio-  
187 economic questions than half-way measures (Jørgensen and Renöfält 2013; Magilligan et al. 2017)  
188 because of the potential loss of recreational benefits or cultural, aesthetic and historical values  
189 provided by the obstacle (e.g. historical heritage of mills, artificial reservoirs creates by the dams  
190 used for fishing, sailing or canoeing).

191 In light of this, the next section will address the ecological challenges raised by the RCR for  
192 diadromous fishes. The following sections will then focus on why RCR for diadromous fishes  
193 should not just be treated as an ecological issue and why, on the contrary, we need integrated  
194 multidimensional approaches (Barthélémy and Souchon 2009) to achieve legitimate and  
195 comprehensive RCR.

196

## 197 **2.2 Three upcoming ecological challenges: a need for tools to support decision making at** 198 **the appropriate scale**

199 Scientific tools to support decision making are crucial for managers (Palmer 2008; Suding 2011).  
200 Consequently, there is a need to develop tools to predict the ecological outcomes of management  
201 options. For RCR, this raises three different challenges: (i) the need to work at an appropriate  
202 spatial scale, (ii) the need for comprehensive quantification of the impact of obstacles on  
203 diadromous fishes, (iii) the need to take these quantifications into account in predictive models.

204

205 2.2.1 First challenge: shifting from ‘site’-based approaches to ‘population scale’-based  
206 approaches

207 The question of scale is a key one in ecology (Levin 1992; Chave 2013) and a key issue for our

208 complete understanding of diadromous fish ecology and conservation (McDowall 2008). The  
209 impact of river fragmentation is generally studied at three biological scales: individual scale, the  
210 population/meta-population scale and the ichthyofaunistic assemblage scale. Though the catchment  
211 scale has sometimes been explored for anadromous species (Buchanan and Skalski 2007; Crane  
212 2009; Susquehanna River Anadromous Fish Restoration Cooperative 2010), surprisingly, the impact  
213 of obstacles on diadromous fishes has generally been assessed either at the individual or at the  
214 population scale but focusing on a specific life stage (upstream or downstream migration) and at the  
215 obstacle or river section spatial scale. Since population dynamics processes operate at these scales,  
216 working at smaller scale can impair the ability to assess the effect of obstacles on diadromous  
217 population dynamics and on their viability. This is even more crucial as the dendritic nature of  
218 rivers implies that obstacles and restoration actions in specific sites of a catchment interact in  
219 complex ways (Fagan 2002; Labonne et al. 2008; Kemp and O’Hanley 2010), and consequently, the  
220 effect of several RCR actions is not necessarily equal to the sum of individual restoration effects  
221 (Kuby et al. 2005; O’Hanley and Tomberlin 2005; Palmer and Bernhardt 2006). In the light of these  
222 kinds of findings, there is clearly a need to upscale RCR for diadromous fishes from a local  
223 approach to a catchment scale thereby bringing this form of restoration in line with calls to upscale  
224 aquatic ecosystem restoration more generally (Friberg et al. 2017).

225

226 2.2.2 Second challenge: considering indirect impacts of obstacles on diadromous fishes

227 There is an abundant literature about the impact of obstacles on diadromous fishes. Two types of  
228 impacts have mainly been studied: direct mortality due to downstream passage through hydropower  
229 facilities, either at the obstacle scale (Travade et al. 1987; Čada et al. 2006; Dedual 2007; Svendsen  
230 et al. 2011) or at the river section scale (Blackwell et al. 1998a; McCleave 2001; Buchanan and  
231 Skalski 2007; Welch et al. 2008; Rechisky et al. 2009; Holbrook et al. 2011; Pedersen et al. 2012),  
232 and fish blockage at upstream migration that impairs or delays the completion of the migration.  
233 However, beyond turbine mortality or blockage at upstream migration, obstacles can have other

234 more indirect impacts such as over-predation, (Agostinho et al. 2012; Drouineau et al. 2015),  
235 overfishing (Briand et al. 2003; Garcia De Leaniz 2008), stress, diseases, energetic costs (Budy et  
236 al. 2002) or selective pressure (Caudill et al. 2007; Podgorniak et al. 2015).  
237 These indirect impacts can be significant. For example, energetic costs can impair reproduction  
238 success for eels, salmon or shads, which stop feeding during reproduction migration (Bracken and  
239 Kennedy 1967; Quignard and Douchement 1991; Kadri et al. 1995; Bruijs and Durif 2009).  
240 Recently, Mateo et al. (2017) showed that obstacles to eel upstream migration can indirectly  
241 severely impact spawning stock biomass even without direct mortality. Regarding eel downstream  
242 migration, Drouineau *et al.* (2017) pointed out that indirect impacts are potentially as important as  
243 direct impacts and, that they too, should be taken into account in the future when assessing the  
244 impact of obstacles. Restricting the impacts of mortality to direct mortality can lead to an  
245 inadequate quantification of those impacts and therefore to an inappropriate prioritization of  
246 management actions.

247

### 248 2.2.3 Third challenge: a need for tools to support decision-making

249 We have seen that RCR for diadromous fishes should be considered at the river basin scale and that  
250 indirect impacts of obstacles should not be neglected. At such a large spatial scale, managers need  
251 tools to support and prioritize decisions (Doyle et al. 2003; Kemp and O’Hanley 2010). Kemp and  
252 O’Hanley (2010) made a review of existing tools to prioritize management actions. They  
253 distinguished three main kinds of approaches. Criterion-based approaches used a set of indicators to  
254 evaluate the impact of each obstacle independently and, to some extent, to their cumulative impacts  
255 (Nunn and Cowx 2012). While these methods are generally easy to implement, they tend to neglect  
256 the complexity of river networks and population dynamics. A second family of approaches relies on  
257 GIS (Brevé et al. 2014) and more-recently graph theory (Segurado et al. 2013). While these  
258 approaches can be applied at a large scale and produce appealing maps to support decision-making,  
259 they generally suffer from an improper consideration of fish movements and population dynamics,

260 and from a limited ability to describe the impact of obstacles on fishes. The optimisation method  
261 (Kuby et al. 2005; O’Hanley and Tomberlin 2005) is a third method which appears very relevant  
262 despite a higher computation cost. This is based on a model that quantifies the benefits of different  
263 restoration actions on one of several criteria such as available habitats (O’Hanley and Tomberlin  
264 2005), but also economic criteria such as minimal loss of hydropower and storage capacity (Kuby et  
265 al. 2005). A numerical optimizer can then be used to objectively to find the sets of restorations  
266 actions that maximize outcomes (Zheng et al. 2009).

267 Different models can be used in conjunction with the optimizers. A common approach is to use a  
268 statistical species distribution model (SDM) that assesses the impact of obstacles on the distribution  
269 of diadromous fishes in a river catchment (Segurado et al. 2014; Clavero and Hermoso 2015). This  
270 approach is suitable when historical data are available and can be used to prioritize management  
271 actions. However, similarly to the call for the development of predictive mechanistic SDM (Keith et  
272 al. 2008; Thuiller et al. 2008; Franklin 2010), the development of mechanistic models that combine  
273 river fragmentation and diadromous fishes population dynamics is a challenge to predict ecological  
274 effectiveness of management measures and support decision-making at the river basin scale. Such  
275 models are required to account for population dynamics and fish movement (Letcher et al. 2007).

276 Similarly to SDMs, mechanistic models can provide complementary results to correlative  
277 approaches, and enhance predictive ability (Kearney et al. 2010; Rougier et al. 2015).

278 In view of this, there is an obvious need for mechanistic model that accounts for fish movements  
279 and population dynamics, dendritic structure of fragmented river networks, direct and indirect  
280 impact of obstacles to (i) assess the impact of obstacles at the obstacle scale and at the population  
281 scale and to (ii) predict the effect of restoration actions. These models can then be coupled with an  
282 optimization tool to support decision-making.

283

## 284 **2.3 RCR and diadromous fishes much more than an ecological issue**

285 2.3.1 RCR and diadromous fishes: interactions of regulations and regulators

286 In addition to the increasing numbers of regulation on ecological continuity that target diadromous  
287 fishes, many kinds of regulation, implemented at different spatial scales, also target diadromous  
288 fishes. For example, the Natural Habitats (Natura 2000) Directive (92/43/EEC), a directive that  
289 aims at protecting biodiversity, imposes on each MS of the EU to draw up a list of sites hosting  
290 natural habitats and wild fauna and flora of interests. Many diadromous fishes are part of the list of  
291 species of interest: for example, sturgeon (*Acipenser sturio*), shads (*Alosa alosa* and *Alosa fallax*)  
292 and lampreys (*Petromyzon marinus* and *Lampetra fluviatilis*). Diadromous fishes conservation is  
293 also targeted by international measures or recommendations: for example, the North Atlantic  
294 Salmon Conservation Organization recommendations, the Bern Convention on the conservation of  
295 European wildlife and natural habitats, the Bonn Convention on the Conservation of Migratory  
296 Species of Wild Animals) or Life projects (LIFE Project on shad 2007-2010 ; Life+ project on shad  
297 2011-2014). Regarding eels, the European Eel Regulation (1100/2007 CE) imposes a new set of  
298 measures on MSs designed to reverse the decline of the European eel (*Anguilla anguilla*) population  
299 by decreasing all sources of anthropogenic mortality, including impacts of obstacles on migration.  
300 Regulations have also been implemented at lower scales. In France, six water agencies manage  
301 water in regional hydrographic districts. They coordinate the district master plan for water  
302 management (SDAGE, “schéma d’aménagement et de gestion des eaux”) - a planned and concerted  
303 water management tool at the basin scale- and river basin water management plans (SAGE,  
304 Schémas d’Aménagement et de Gestion des Eaux) at the river basin scale (Richard et al. 2010). At  
305 this scale, committees for the management of migratory fish (COGEPOMI COmité de GEstion des  
306 POissons MIgrateurs) are in charge of the management of diadromous fishes through the  
307 implementation of migratory fish management plans (PLAGEPOMI/ PLAN de GEstion des  
308 POissons MIgrateurs).

309 Dekker (2016) illustrates the difficulties of this piling up of overlapping regulations and  
310 organisations with the example of the European eel. He suggested that the lack of coordination and  
311 control between these different regulatory scales is potentially a key explanation for failure to

312 achieve efficient restoration of this species. This type of hypothesis thus merits detailed analysis  
313 mobilising social science discipline research techniques and methods. This is particularly so  
314 because challenges emerging from interdependent regulations operating at different scales  
315 managing diadromous fishes are neither specific to France nor to Europe. For example, the  
316 American eel (*Anguilla rostrata*) is both managed at the state and the federal scales in Canada and  
317 in the United States of America and efforts are made to implement a bi-national management (Haro  
318 et al. 2000; MacGregor et al. 2008, 2009). Regarding Atlantic salmon (*Salmo salar*), management is  
319 based on shared stewardship between federal and states governments, First Nations and other  
320 Aboriginal organizations, volunteers, other stakeholders and other federal agencies, and Canada is  
321 also member of the North Atlantic Salmon Conservation Organization, an international organization  
322 aiming at restoring and protecting the Atlantic salmon.

323 All these conservation and restoration regulations potentially interact with one another and,  
324 depending on how they are interpreted by policy actors, can cause policy conflicts. For example,  
325 some wetlands or lakes created by the construction of a dam are classified by Natura 2000 because  
326 of interest for birds or other animals or plants, though they alter fish and sediment free-circulation.  
327 But this regulation may conflict with others, for example on water usage. For example, at the  
328 European scale, Directive 2009/28/CE promotes the use of renewable energy, including  
329 hydropower, though hydropower facilities are often an obstacle to fish free-movement and a source  
330 of mortality to migrant species (Blackwell et al. 1998b; Muir et al. 2006; Larinier 2008; Pedersen et  
331 al. 2012). RCR also potentially comes into conflict with regulations on the spreading of alien  
332 species and diseases (Rahel 2013; McLaughlin et al. 2013; Tullos et al. 2016). Rahel (2013)  
333 provides many interesting examples on how fragmentation was used by managers to prevent the  
334 spread of diseases in Norway, Czech Republic or United States. In Europe, this issue is especially  
335 important for fish farming aquaculture: the European Directive 2006/88/CE defines the condition  
336 that should be fulfilled for a zone to be considered as “disease-free”, granting specific facilities for  
337 aquaculture. Such a zone may either be one or several entire catchments, or a sub-part of the

338 catchment delimited by “a natural or artificial barrier that prevents the upward migration of aquatic  
339 animals”. Consequently, restoring connectivity and migration may question the disease-free status  
340 granted to Finnish, Swedish, Irish, Danish or British areas (European Commission Decision of 15  
341 April 2010). Finally, RCR may interfere with other water usage regulation, especially rules about  
342 minimum discharge and water extraction.

343 Grabosky (1995) mentioned 7 types of potential interactions amongst regulations ranging from  
344 synergy to neutralisation. Understanding interactions between conservation regulation and other  
345 public policy rules is therefore crucial for offering a comprehensive understanding of why RCR  
346 measures can be ineffective. This point has been recently recognised by the European Commission  
347 in its encouragement of the integration of ecosystem restoration agenda within the delivery of major  
348 policy objectives, especially regional development (rural or urban). For example, the 2020 Strategy  
349 for biodiversity and the “Green Infrastructure” both call for a better integration of environment  
350 preservation policy within other public policies on territorial development to achieve a better  
351 reconciliation of environmental and socio-economic targets. Yet, this question of interdependent  
352 regulation goes far beyond a simple ignorance of potential interactions: depending on territories,  
353 stakeholders might choose to favour a policy to the detriment of another one for political reasons.  
354 For these reasons too RCR should not be analysed in a vacuum but integrated within broader social  
355 science evaluations of tensions between public policies and local territorial projects (Carter et al.  
356 submitted; Friberg et al. 2017). This also explains why ‘one size fits all’ strategies do not work to  
357 achieve effective RCR for diadromous fishes.

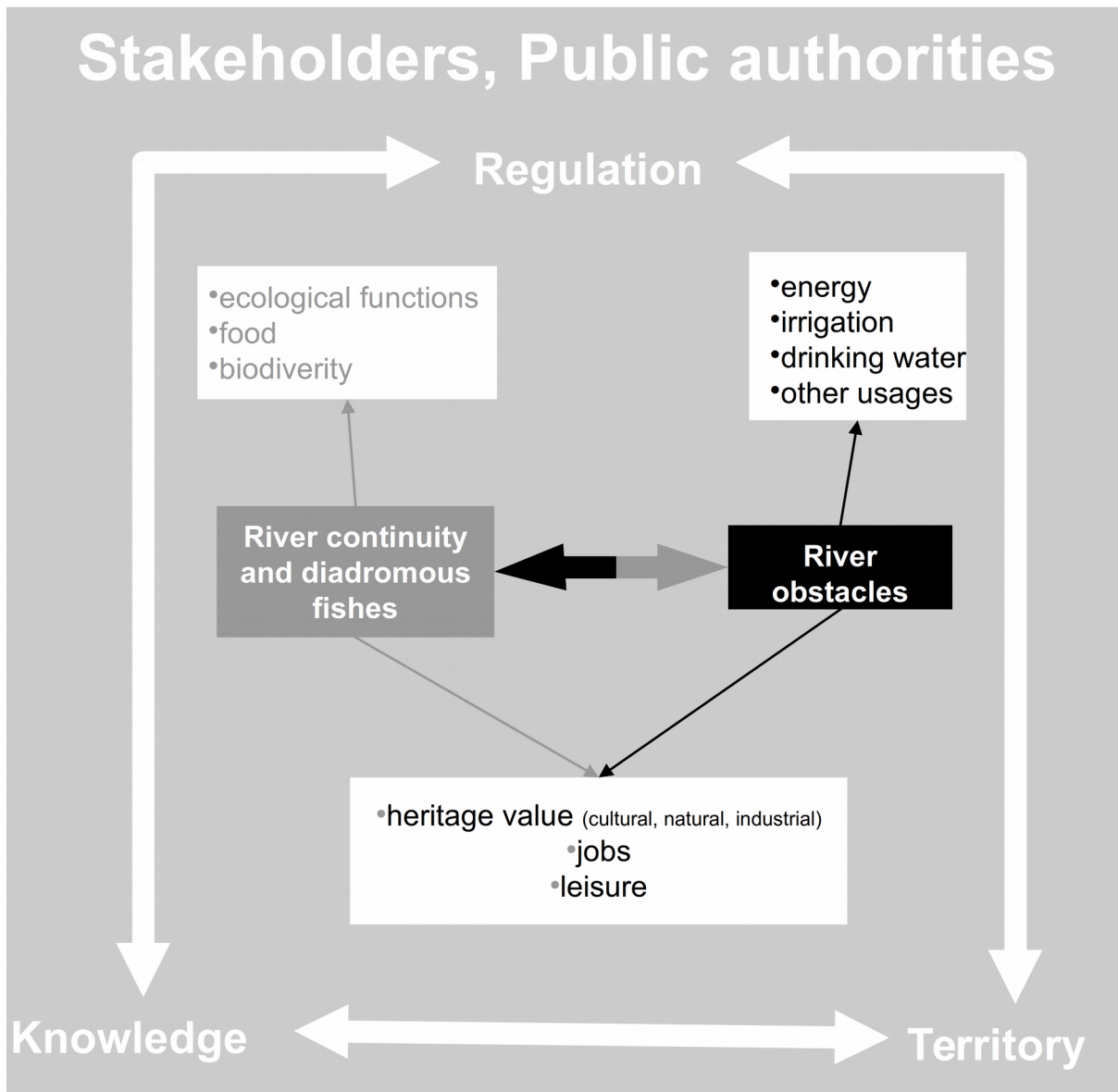
358

359       2.3.2   RCR and diadromous fishes and territorial development: competitions of ecosystems  
360       goods and services

361 Though river connectivity is an ecological concept, RCR is not only an ecological issue but also a  
362 socio-economic issue (Pahl-Wostl et al. 2007; Hermoso et al. 2012; Pahl-Wostl et al. 2013; Wortley  
363 et al. 2013; Olden et al. 2014; Barthélémy and Armani 2015), especially because of the multitude of



364 goods and services provided by rivers. In a context of climate change and increasing tensions about  
365 water use, obstacles have become a cornerstone of competitions between ecosystem goods and  
366 services (Figure 1).  
367



**Figure 1.** Context of river continuity restoration. Both diadromous fishes (dark grey box) and river obstacles (black box) potentially provide ecosystem goods and services (white boxes). The hierarchy given by actors to these competing ecosystem goods and services – and which may change over time - results from political work between stakeholders and public authorities over knowledge, territory and regulation interdependencies.



368 • Assessing ecosystems goods and services supported by diadromous fishes

369 About ten years after the Millennium Assessment, the EU biodiversity strategy for 2020 emphasised  
370 goods and services provided by healthy ecosystems (EU Commission 2011). For example, Target 2  
371 of the EU strategy was aimed at maintaining and restoring ecosystems and their services. In meeting  
372 this target, MSs are required to develop a framework to map and assess ecosystem states and their  
373 services and to better integrate the value of ecosystem services into national and EU accounting and  
374 reporting systems (EU Commission 2011). Ecosystem goods and services tend to become the  
375 quantitative tool to integrate biodiversity into other sectoral policies that may be used to support  
376 decision-making (Turner et al. 2000; Daily et al. 2009; de Groot et al. 2010), to arbitrate trade-offs  
377 between services provided by services (Maes et al. 2012) but also with goods and services provided  
378 by other sectoral activities. As such, ecosystem goods and services can be used as a tool to arbitrate  
379 the trade-offs among interdependent activities impacted by the RCR (Figure 1).

380 However, this raises specific challenge for diadromous fishes. Diadromous fishes provide four types  
381 of ecosystem goods and services (Limburg and Waldman 2009): (i) provisioning of proteins and  
382 other products because of their historic abundance and high catchability during migration, (ii) a  
383 transfer of proteins between marine and continental ecosystems as illustrated by the decomposition  
384 of salmon carcasses that contribute to the development of riparian vegetation, (iii) supporting the  
385 marine food-web and (iv) an important contribution to both indigenous and non-indigenous culture.  
386 These species used to have high market value (McDowall 1988, 1999), but the total income of the  
387 commercial inland fishery has strongly declined because of the collapse of populations (Champion  
388 1999; Boisneau and Mennesson-Boisneau 2001). Meanwhile, other goods and services provided by  
389 diadromous fishes, such as cultural services, are potentially becoming more prominent and the  
390 value of diadromous fishes should not be restricted to their commercial value. Therefore, there is a  
391 need to quantify and qualify new emerging non-market values such as cultural, recreational and/or  
392 territorial values. For example, McClenachan et al. (2015) pointed out that the economic benefit in a

393 case of alewives restoration was only a small portion of the overall social benefits for stakeholders.  
394 While the turnover generated by the fishery used to be more or less proportional to catches, and  
395 therefore to fish abundance, the relationship between fish abundance and the quantity of cultural or  
396 recreational value they provide is less obvious. The dramatic decline in the market values of  
397 diadromous fishes urges (i) updating the ecosystem goods and services directly associated with  
398 diadromous fishes and obstacles (ii) based on traditional methods used to quantify non-market  
399 ecosystem goods and services, developing a method to assess ecosystem goods and services  
400 provided by diadromous fishes and RCR. This framework could be developed around well-honed  
401 methods to elicit non-market values, such as choice experiment analysis (Adamowicz et al. 1998;  
402 Cameron et al. 2002; List et al. 2006) and could take into account both their uses evolution  
403 including economic/productive and environmental, and stakeholders' needs and expectations. Then,  
404 indirect goods and services impacted by RCR could be listed and quantified and the relationship  
405 between fish abundance and quantity of services elicited.  
406 This challenge is crucial to carry out costs-benefit analysis of RCR for diadromous fishes, and  
407 consequently to support decision-making.

408

- 409 • Understanding the social construction of RCR to identify political opportunities and points  
410 of tension

411 Whereas, as we have argued, public policies and regulation play a critical role in structuring RCR  
412 actions, in fact knowledge gaps exist concerning political processes leading to their implementation  
413 which are often invisible in practice and little studied in the literature. Indeed, few studies have  
414 focused expressly on the link between ecosystem restoration and the politics of implementation of  
415 public policy (Baker and Eckerberg 2013). Even less have focused on ecosystem restoration as a  
416 territorial project (Germaine and Barraud 2014; Germaine and Lespez 2014). A critical challenge is  
417 grasping RCR analytically as a social construction. On the one hand, scholarship has shown the  
418 limits of functionalist accounts linking actors' incentives to policy contents: it is not possible to

419 explain the origins and contents of policies based purely on their functions (Bartley 2007).  
420 To illustrate this point, we can argue that from a functionalist perspective, the EU WFD and Blue  
421 and Green infrastructure are the results of the functional imperatives of European and French  
422 authorities to restore ecological continuity, therefore the efficiency of this measure will be directly  
423 assessed regarding economical or ecological outcomes, as in a DPSIR framework (OECD 1993;  
424 Gari et al. 2015). By comparison, from a constructivist approach, both the formulation and the local  
425 implementation of the WFD and the Green and Blue Infrastructure result from complex political  
426 action of many actors (European and French public authorities, local stakeholders, scientists...), and  
427 their contents must be explained as contingent ‘settlements of conflicts’ (Bartley 2007) over both  
428 ecological continuity and potentially also other regulations. This is because actors’ interests are  
429 neither fixed nor can they be assumed: rather they are built in interaction with others’ and are  
430 *socially constructed* (Eckersley 2004). In the case of RCR, through their collective interaction over  
431 policy implementation, actors’ interests and understandings of fish, obstacles and rivers can  
432 transform and change.

433 On the other hand, RCR is not disconnected from other political projects but takes place in relation  
434 to other territorial projects and river management plans. Conflicts and tensions can emerge between  
435 industrial actors and public policies (e.g. when RCR causes tensions with sectoral policy objectives)  
436 and over the relative importance of RCR for a community (e.g. in some places RCR has been  
437 viewed favourably, McClenachan et al 2015; in others not, Fox et al, 2010). For example, the  
438 opposition of fish farmers to RCR does not necessarily relate to the direct issue of ecological  
439 continuity but to a connected issue of disease dispersal in river networks. Therefore, constructivist  
440 approaches postulate that the link between a public authority, an official objective and a regulation  
441 is not a linear one, and must be analysed in a more comprehensive way, and may change through  
442 time. This understanding is necessary to identify tensions and incentives to achieve efficient  
443 reviews.

444 To provide critical understandings about the social construction of interests towards RCR and their

445 outcomes, including how actors manage potentially conflicting policy processes, research can  
446 usefully draw upon the well-honed concept of ‘political work’ (Jullien and Smith 2014) used in  
447 public policy analysis. Political work is defined as action by public and collective private actors to  
448 translate their immediate local concerns into public problems and which demand public regulatory  
449 responses (e.g. public policies). Political work involves a number of activities including the making  
450 of arguments to put issues on the political agenda ; the forging of alliances with other actors ; the  
451 establishment of new decisional structures ; strategies of mediatisation and public speeches  
452 advancing and justifying actor positions held. Actors’ political work can be aimed at putting in place  
453 new public policies, implementing public policies already in place, changing public policies,  
454 countering public policies. As an illustration, in the context of the RCR, the political work of some  
455 NGOs over RCR can consist in strategies to promote the restoration of continuity in opposition to  
456 other stakeholders, while at the same time promoting the development of renewable sources of  
457 energy in the context of energy transition. These links are crucial, especially in the current period of  
458 increasing involvement of local stakeholders in river management after decades of distant  
459 relationships (Zylberblat et al. 1996; Blackstock and Richards 2007; Pahl-Wostl et al. 2007;  
460 Germaine and Barraud 2014). Studying political work can therefore enable research to generate  
461 understandings about how successful RCR projects came to be successful (i.e. going beyond the  
462 question of social benefits of projects once implemented) and/or about lines of conflict and tension  
463 which require to be addressed to bring about future change.

464 In a regulatory context, when the EU biodiversity strategy for 2020 (EU Commission 2011) calls  
465 for a better integration of biodiversity protection into major public policies, social science can and  
466 should provide valuable insights on how RCR impacts on-going territorial construction processes  
467 led by different or competing actors at different scales and whether RCR is altering peoples’  
468 relations to rivers and diadromous fish. This is a critical point, especially responding to climate  
469 change and increasing tensions around water use that may modify choices and priorities. For  
470 example, the decline of the abundance of diadromous species may either lead to a reinforcement of

471 management actions (McClenachan et al. 2015) or to a loss of societal interest for these fish leading  
472 to loss of oversight of their decline. This last threat was defined as “ecosocial anomie” by Limburg  
473 and Waldman (2009). But, we contend, to assess whether migratory fish hold any cultural value will  
474 require social science analysis of political work of actors on RCR in different places compared. The  
475 example of the Scottish fishery (Carter 2014) is a very instructive example of a largely  
476 unpredictable mobilization of actors through political work that lead to deep modification of  
477 management and sustainable fisheries. Also within the example of Scottish-EU fisheries, Carter  
478 (2013) demonstrated how insights from constructivist approaches can identify lines of tension  
479 blocking implementation as well as opportunities for major change. Building on such approaches, a  
480 challenge to achieve effective RCR is to map political work socially constructing RCR for  
481 diadromous fishes, by describing actors networks, arguments, expectations and preferences over  
482 time. This task is required to elicit formal and informal links between stakeholders and how they  
483 manage interdependencies between possible divergent policy objectives, between territories and  
484 between knowledge forms (Carter et al. submitted). By doing this, research can identify the ‘type’  
485 of political work around RCR and diadromous fishes; ‘how’ and ‘why’ incentives and conceptions  
486 of restoration and ecosystem services’ values may vary and the consequences for effective  
487 integration in particular territories. In so doing, it can point out the for legitimate RCR, conflicts  
488 blocking effective implementation, and potentially new types of incentives to achieve effective  
489 RCR.

490

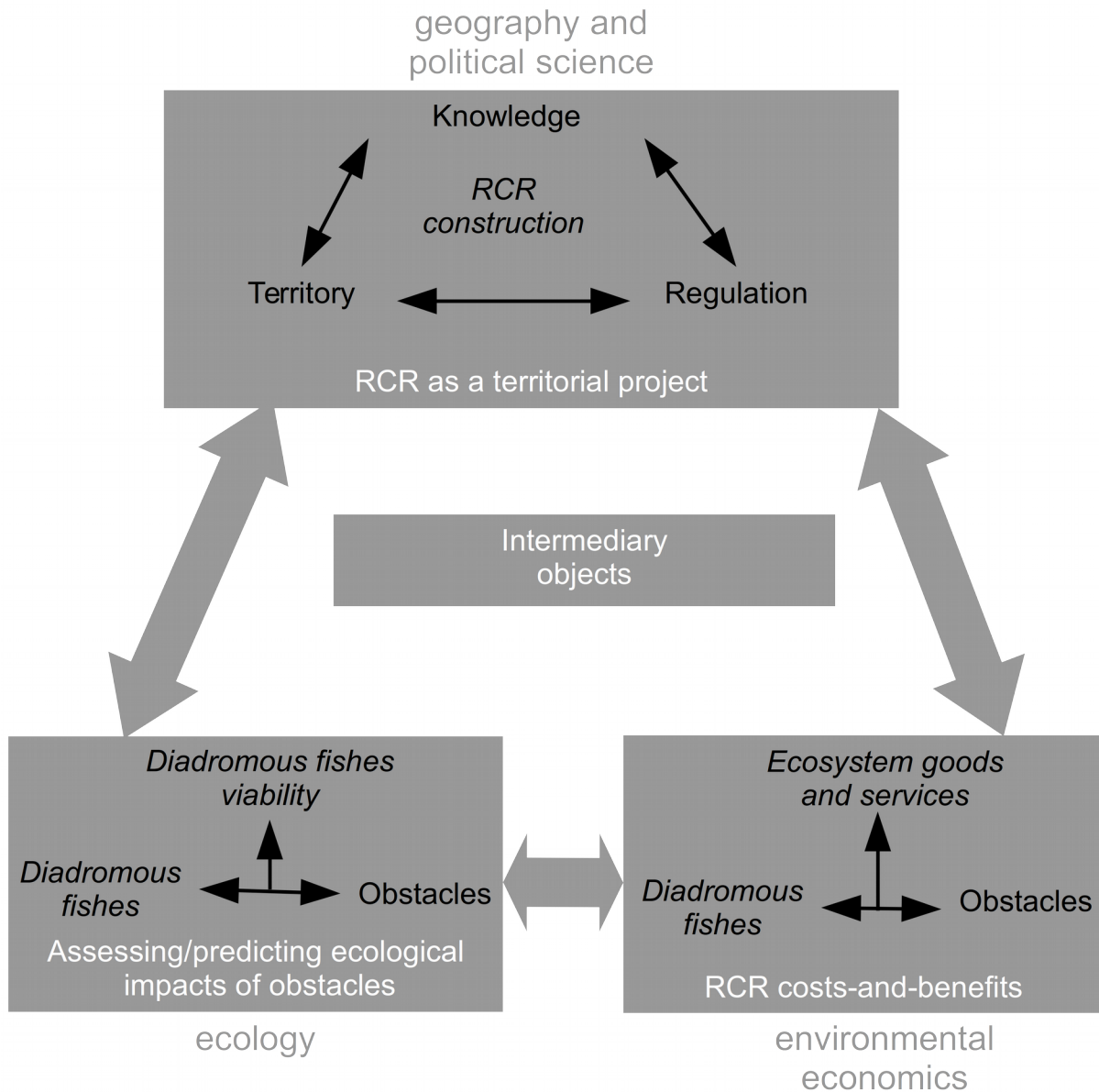
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## 492 **2.4 Proposing tools to move beyond traditional disciplinary frontiers and achieve a** 493 **multidimensional approach to RCR**

### 494 2.4.1 Organising knowledge flows between disciplines

495 We have listed three types of challenges in three different fields and which more or less correspond  
496 to three groups of disciplines: ecology, environmental economics and geography/political science

497 around the question of RCR and diadromous fishes (Figure 2). Each discipline provides unique  
498 insights on RCR. However, a comprehensive analysis requires that these insights are collectively  
499 organised in a coherent way. This is especially true since each discipline needs the results provided  
500 by the others for effective RCR evaluation. Consequently, it is important to acknowledge that  
501 disciplines are interdependent.  
502



503

**Figure 2.** Conceptualising, evaluating and achieving RCR for diadromous fishes require interdisciplinary exchanges. Each discipline can provide different results (ecology: quantification of the ecological outcome of restoration, environmental economics: valuation in terms of ecosystem

goods and services, geography and political science: regulation, territories, actors and political work, specifying actors and arguments either ‘in favour’, ‘against’ or ‘indifferent’ to RCR).

504

505 Ecology is required to quantify and predict the effect of RCR on the abundance of diadromous  
506 fishes. Through the economical quantification of market and non-market values of diadromous  
507 fishes, their abundance can then be converted into goods and ecosystem services that can be used to  
508 manage trade-off between conflicting services. To elicit and understand these trade-offs and their  
509 shifts through time, geographers and political scientists can provide insights on the social  
510 construction of the restoration program and more specifically of the objectives of the different  
511 stakeholders and the temporal and spatial scales of political activity in territories. In turn, this  
512 analysis of the social construction of RCR requires spatial information on ecological factors (such  
513 as the spatial zones of ecological importance, the ecological importance of species or their  
514 interactions with other species) and economical ones (for example, economic valuation of services  
515 of services).

516 To organise the necessary exchange of knowledge and moreover, the sharing of assumptions among  
517 disciplines, we propose using cross-disciplinary knowledge flows (Figure 2). These are flows of  
518 questions and results and visions of the problems encountered by each discipline and which are  
519 communicated to the others. This does not necessarily happen spontaneously. To facilitate the  
520 process, we propose working with “intermediary objects” (Vinck 1999). In collaborative networks,  
521 intermediary objects refer to objects that are meaningful for all actors of the network, though their  
522 meaning can vary among actors (Vinck and Jeantet 1995; Vinck 1999; Boujut and Blanco 2003;  
523 Eckert and Boujut 2003; Vinck 2003; El-Kechai and Choquet 2006). They have proved to be  
524 valuable mediation tools among disciplines or domains, enhancing communication among them by  
525 facilitating translation and a support to share a representation of problems (Boujut and Blanco 2003;  
526 Buller 2009). Typically, in the case of the RCR, since spatial and temporal scales are especially  
527 important, maps and timelines are among the most relevant intermediary objects. The co-



528 construction of maps is a way to share visions of territories: each discipline can show on a same tool  
529 where and why specific zones are of interest (spawning grounds, administrative delimitation,  
530 implantation of an enterprise, conflicts...). Regarding a map of obstacles, while the geographical  
531 position is common to any discipline, the attributes of interest for the different disciplines are  
532 different (for example, passability in ecology, turnover in economy, cultural value in geography).  
533 Maps of actors are also useful tool for identifying the role and importance of different stakeholders  
534 and public authorities form a multidimensional perspective. Building a multidimensional timeline is  
535 a way to establish relationship between events from different fields. Listing and co-constructing  
536 intermediary objects can therefore be useful to achieve a comprehensive view of RCR in territories.

537

#### 538 2.4.2 Addressing the complexity of spatial and temporal scalar interactions

539 We outlined earlier the major importance of time and space for restoration programs. Consequently  
540 scale integration is a major challenge in a multidisciplinary approach of RCR. Regarding  
541 diadromous fishes and RCR, the river basin scale seems to be a central integrative scale. This is  
542 both an ecological (population or sub-population scale) and physical/hydrological scale. The river  
543 catchment scale also corresponds to water administrative units. Hydrographic districts were  
544 introduced in the context of the Water Framework Directive, and correspond to one or several  
545 adjacent river basins in which MSs were required to implement River Basin Management Plans  
546 (presently, the plans cover the period 2009-2015). Finally, river basins tend also to be a political  
547 unit. Water and its governance is a cornerstone issue in the territorialisation process (Ghiotti 2006)  
548 and the notion of basin common principle is a key argument in many political constructions. For  
549 example, each Water Agency in France has articulated a specific understanding of the river basin  
550 common interest (Meublât and Lourd 2001; Bouleau 2014). In this context, the basin scale appears  
551 to be the landscape scale advocated by Perring *et al.* (2015) when calling for a scaling-up of  
552 restoration activities. It appears to be a unit scale common to the multiple dimensions involved in  
553 RCR. However, it will be necessary to understand how this central scale interacts with other spatio-



554 temporal scales to achieve effective RCR for diadromous fishes. For example, while a river  
555 catchment is a water administrative unit, it does not match the geographical scale of administrative  
556 regions, nor other issues which are relevant for territorial development such as the governing of  
557 agriculture or fish farming. Moreover, the definition of basin might vary depending on questions  
558 and mobilizations (Fernandez et al. 2014; Bréthaut and Pflieger 2015). In this context of interacting  
559 scales in multiple dimensions, scale should not be seen only as an “euclidean distance” or  
560 “temporal-distance”, but also as a relational concept which sees space as the result of sociological,  
561 ecological or biospherical relationships (Healey 2004). Places, sites and territories are not seen as  
562 geographical units but as a social-construct with meanings specific to the social context. The co-  
563 construction of intermediary objects such as maps, networks of actors and timelines should favour  
564 the understanding of scalar interactions around the river catchment scale. This is particularly  
565 important as the challenges of scalar interactions are not, as is sometimes implied, merely a matter  
566 of coordination, and being legitimate at one scale does not necessarily mean being legitimate at  
567 another (Carter et al. submitted).

568

#### 569 2.4.3 Reconciling constructivism and functionalism to achieve efficient restoration

570 A specific challenge emerges bringing about knowledge flows in the case of RCR. This is because  
571 whereas ecological and economic valuations are frequently based on functionalist approaches, this  
572 is not necessarily the case for political science and geography. As we have argued, it has been well  
573 documented that river restoration is a social construction. Recognising this is especially important  
574 for building multidisciplinary evaluations of effectiveness. Since RCR is a social construction, an  
575 example of success or failure in one territory does not mean that the same approach would  
576 necessarily have had the same results in an other context: “one size does not fit all”. For example,  
577 Blackstock *et al.* (2012) have shown that the process of implementing a program can be just as  
578 important for stakeholders as its outputs and, moreover, that effectiveness of outputs is directly  
579 associated by stakeholders with effectiveness of inputs.

580 Although all disciplines recognize the need for multiscalar and multidimensional approaches, the  
581 integration between functionalist and constructivist approaches is not straightforward because of  
582 ontological and methodological differences. Traditional frameworks support restoration planning,  
583 such as DPSIR and related frameworks (OECD 1993; Gari et al. 2015) or PCDA (Plan-Do-Check-  
584 Act) are generally based on linear causal relationships from an anthropogenic pressure to the  
585 implementation of a restoration measure. These functionalist approaches, consistent with some  
586 ecological and economical ontologies, have proved to be useful and efficient to describe systems  
587 and provide tools to support restoration planning. However, they lose their usefulness as soon as  
588 they confuse their simplified and static version of the world with an accurate description of reality.  
589 This is even more critical when evaluating the effectiveness of RCR since initial objectives and  
590 causal links may have changed through time.

591 Consequently, there is a need for new frameworks that aim to conciliate the constructivist point of  
592 view as upheld in some strands of political science and geography with the more functionalist  
593 approach of natural and economic science. It is not only a methodological challenge that would  
594 consist in lining up deliverables of a different nature (especially quantitative and qualitative results)  
595 but the development of a new framework based on two antagonistic ontologies, to achieve effective  
596 RCR for diadromous fishes. Once again, the co-construction of cross-disciplinary knowledge flows  
597 and intermediary objects can be critical elements of such frameworks to elicit, and hence make  
598 visible, complementarities between different ontologies.

599

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603

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