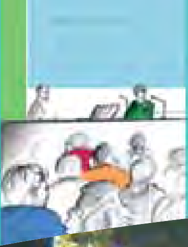
ONEMA

Meeting

Recap



Diagnosing and restoring aquatic biodiversity

Recap of the symposium titled "The outlook for managing aquatic biodiversity in rivers and lakes".
Paris, 14-15 November 2012

Nicolas Poulet, Nirmala Séon-Massin and Laurent Basilico

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The symposium titled "The outlook for managing aquatic biodiversity in rivers and lakes" was organised by Onema (National agency for water and aquatic environments), with assistance from IOWater (International office for water). The symposium was held in Paris, on 14-15 November 2012.

This document may be consulted on the Onema site (www.onema.fr), in the Publications section. It may also be found at the national portal for "Water technical documents" (www.documentation.eaufrance.fr).

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Foreword

From mountain torrents to low-land rivers, from Alpine lakes to coastal lagoons, French aquatic environments present a tremendous array of animal and plant species. This biodiversity consists of complex and fragile equilibria between the living communities and their habitats. It informs on the health of natural environments and is of the utmost importance for human society in terms of the natural heritage, culture, the economy, tourism, etc. At a time when the need to reconcile human development and the preservation of natural environments is acknowledged by one and all, biodiversity and notably aquatic biodiversity is confronted with major threats. In just a few decades, the rapid extension of urbanisation and the development of intensive agriculture and industry have harmed environments by modifying river banks, spreading contaminants in ecosystems, increasing pressures on water resources, etc. Climate change, which in France has already resulted in more severe low-flow conditions and considerable temperature rise in water bodies, constitutes an increasingly unsettling factor. The globalisation of trade and the creation of new trade routes has resulted in unprecedented mobility of plant and animal species. The increasing presence of alien species, some of which turn out to be invasive, is yet another disturbance that affects aquatic environments.

In this context of global change, what is the actual status of biodiversity in France? How will current and future changes in the climate affect fish populations, plants and plankton communities? What will be the effects of biological invasions on aquatic biodiversity? What will be the consequences of changes in discharge regimes and in river hydromorphology? How can the managers of aquatic environments assess these impacts? And how can they work to limit the effects and to restore biodiversity, both now and in the future?

All the above questions were addressed by the symposium titled “The outlook for managing aquatic biodiversity in rivers and lakes”, organised by Onema on 14-15 November 2012 in Paris with over 200 participants from research institutes, State services, local governments, companies and NGOs. The two days of discussions between scientists and water managers were an occasion to present some 30 partnership-research projects on aquatic biodiversity. Following a status report on biodiversity in aquatic environments, the speakers presented a range of innovative tools for monitoring and restoring biodiversity in a context of global climate change. This document recapitulates the knowledge, methods and results presented during the meeting, as well as the many questions raised by all this new information.

The European tree frog (Hyla arborea), *an EU-listed species (Annex IV of the Habitat directive) and its habitats are protected nationwide.*

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Contents

Threats to aquatic biodiversity are increasingly acknowledged by public policies

Worldwide, biodiversity has suffered a number of setbacks, notably since 1900 with the extinction of numerous plant and animal species. In 2012, of the 65 500 species analysed by the IUCN (International union for the conservation of nature), over 20 200 were threatened with extinction. A large part of the scientific community is of the opinion that the current period is the sixth great biodiversity crisis, the last having seen the end of the dinosaurs at the end of the Cretaceous period 65 million years ago. However, the situation today is not the product of natural geophysical upheaval or climate change, it is the direct result of the rapid development of human societies and activities following the industrial revolution.

Social development has all too often been at the expense of aquatic environments.

It is not always easy to identify pollutants, e.g. *micro-pollutants.*

Just in the last few decades, urbanisation and the “artificialisation” of territories, intensive agriculture and depletion of resources have placed unprecedented pressures on the natural balances of environments. Piling up on top of these pressures, already today and increasingly tomorrow, are the climate disturbances caused by anthropogenic increases in the concentrations of greenhouse gases, at a time when global trade has artificially accelerated the mobility of species that in some cases turn out to be invasive and whose importation is a further factor affecting ecosystem balances.

Aquatic biodiversity is often on the front lines in confronting these global changes. Rivers, lakes and ponds are geographically isolated areas that concentrate a wide variety of ecosystems and species ranging from water birds to fish populations and from river plants to plankton communities. Water, the enabling medium for these many life forms, is also a vital resource for humans that is increasingly abstracted for drinking water, irrigation and industry. Aquatic environments receive, either via drainage or run-off, a significant percentage of the pollutants present in the basin.

A few examples of the pressures and impacts weighing on aquatic environments.

Lying at the crossroads between social and economic issues, rivers have seen their beds and their operation severely altered by weirs and locks for navigation, impoundment and channelling, hydroelectric dams, etc.

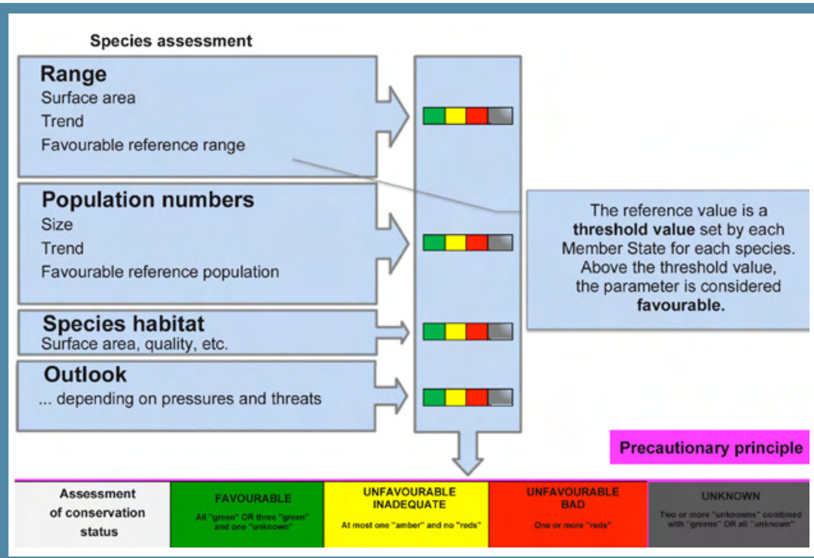
Public opinion has become increasingly aware of the need to preserve and restore biodiversity and public polices now see biodiversity as an essential factor in sustainable development. On the international level, the Convention on Biological Diversity, drafted during the Earth summit in Rio de Janeiro in 1992, has now been ratified by 176 countries. France signed the convention in 1994 and published its first National biodiversity strategy (SNB) in 2004. The SNB divided the Rio commitments into ten action plans focussing on the natural heritage, agriculture, international affairs, urbanism, land-based transportation infrastructure, oceans, forests, overseas territories, research and tourism. Following the Grenelle environmental meetings, the SNB was revised in 2010 to include the concepts of biological corridors and networks of protected zones. The strategy is closely tied to the European directives on biodiversity which constitute remarkable operational tools for management and restoration. The first to be adopted was the Birds directive in 1979 just after the Berne convention on the conservation of European wildlife and natural habitats. The next was the Habitats directive in 1992, the cornerstone for the protection of biodiversity in the EU which led to the creation of the network of Natura 2000 special conservation zones (SCZ) (see the box below). The second Habitats-directive report at the end of 2013 will contain an assessment on the conservation status in France of 93 plant species, 199 animal species and 132 EU-listed habitats. Concerning aquatic environments, the above cross-cutting management tools were joined by the more specific Water framework directive (WFD), adopted in 2000, which guides EU efforts to restore the good chemical and ecological status of water bodies. Though it does not focus exclusively on the issue of aquatic biodiversity, the very proactive directive has made the restoration of living communities, notably through the development and systematic use of bioassessment tools, a major condition to achieving the goal of good ecological status for water bodies.

Second report for the Habitats directive coming soon

The EU adopted the Habitats directive in 1992 to "contribute towards ensuring biodiversity through the conservation of natural habitats and of wild fauna and flora in the European territory" (article 2). The directive targets the conservation of 132 types of habitat (including 11% of aquatic habitats) making up the network of Natura 2000 special conservation zones, plus 292 plant and animal species (including 8% of fish and 9% of amphibians). In France, the Natura 2000 network was set up in 2006 and comprises over 1 500 sites representing 11% of continental France (including the special protection zones for the Birds directive). The successive reports, required by the directive (article 17), constitute major way points and require an analysis of the conservation status of habitats and species throughout the country, in the form of an assessment document including numerical data on the four selected criteria, *i.e.* range, population, habitats and outlook (for species), and range, surface area, structure/function and outlook (for habitats).
The first French report (2006-2007) was drafted under difficult conditions. The task was new and raised a number of complex questions, *e.g.* the reference values and the notions of habitat structure and function could rarely be quantified and many of the fields in the report were filled in on the basis of expert opinion.

For the second report (2012-2013), the people in charge can now call on the first national assessment of "exceptional" biodiversity and on a wide array of data sources available in France, *e.g.* the WIS-FR database, new environmental atlases, summaries of the DOCOB documents (management plans for Natura 2000 sites), etc. The fine tuning of the monitoring system is a major objective for the first half of 2013. The system must make it possible to assess the value of the various sources of data for the report, to produce additional data-collection protocols if necessary and to guide the selection of monitoring networks and assessment tools providing comparable data on current status, pressures, functions, etc.For the aquatic environments in the Natura 2000 network, the analysis is being carried out jointly by Onema and MNHN (National museum of natural history). Starting with a complete review of the scientific literature, a group of experts then established a method that was field tested and adjusted as needed. The goal was to produce standardised methods available to all participants in order to obtain a consistent assessment for the entire country.

Figure 1. Assessment system of the Habitats directive for plant and animal species.



The creation of this regulatory framework provides water managers with operational goals that promote aquatic biodiversity. In the process, it has also created new needs in terms of scientific knowledge and specific tools, *e.g.* temporal analyses, new methods for in situ surveys, new biodiversity assessment tools, restoration work, local studies on specific pressures, special monitoring programmes, etc. A great deal of research work on the above topics has been invested over the past few years in the EU. In France, Onema has managed and/or funded a large part of the research work, often in conjunction with WFD implementation. The symposium titled "The outlook for managing aquatic biodiversity in rivers and lakes", organised by Onema on 14-15 November 2012, was an occasion to review recent results and the directions taken by current research via some 30 presentations, followed by debates. Following a status report on biodiversity in aquatic environments in France, this recap document presents a range of innovative tools for monitoring and restoring biodiversity. It then goes on to discuss project feedback and data on the complex links between aquatic biodiversity and climate change, divided into three broad topics, namely climate change, habitat degradation and invasive species.

1 Status report on aquatic biodiversity in France

What is the current status of biodiversity in French rivers and lakes? The first part of the symposium drew up a status report for France as a whole.

Making extensive use of data, the French IUCN committee (International union for the conservation of nature) opened de session with a presentation of the worrisome situation for many aquatic species, including both endemic species, such as the Rhône streber (*Zingel asper*) and the Lez sculpin (*Cottus petiti*), and species that were once common and abundant such as the eel (*Anguilla anguilla*) and white-clawed crayfish (*Austropotamobius pallipes*).

However, the negative situation can be partially tempered by a number of positive time trends observed in continental France for many fish species, including an array of exotic species. The analysis of these general trends can be improved locally thanks to the availability of long-term monitoring data. Of interest is the discovery of several native species that had gone unnoticed in families that were thought to be fully examined, *e.g.* gudgeons (*Gobio* spp.) and minnows (*Phoxinus* spp.). However, their conservation status remains to be assessed.

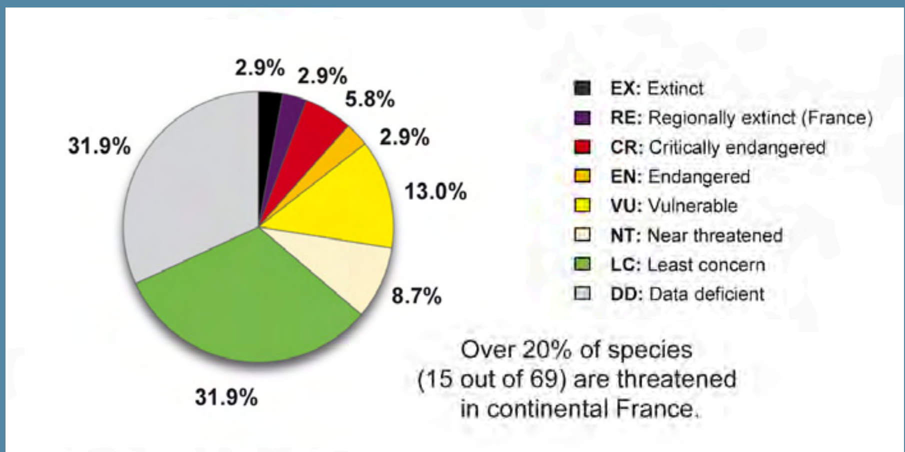
1.1 – Numerous threatened species

EIn continental France, 15 species of freshwater fish out of 69 native species, *i.e.* over 20%, are today threatened according to the French IUCN committee (Figure 2). Four are critically endangered, namely the European eel (*Anguilla anguilla*), European sturgeon (*Acipenser sturio*), Rhône streber (*Zingel asper*) and Lez sculpin (*Cottus petiti*). The weather loach (*Misgurnus fossilis*) and the Corsican trout are “endangered”, whereas a number of flagship species are considered “vulnerable”, *e.g.* pike (*Esox lucius*), Atlantic salmon (*Salmo salar*) and Arctic charr (*Salvelinus umbla*). The assessment could not be carried out on almost 32% of species because of insufficient data, a high proportion due to the recent description of cryptic species (see the Spotlight on taxonomic difficulties at the end of this section).

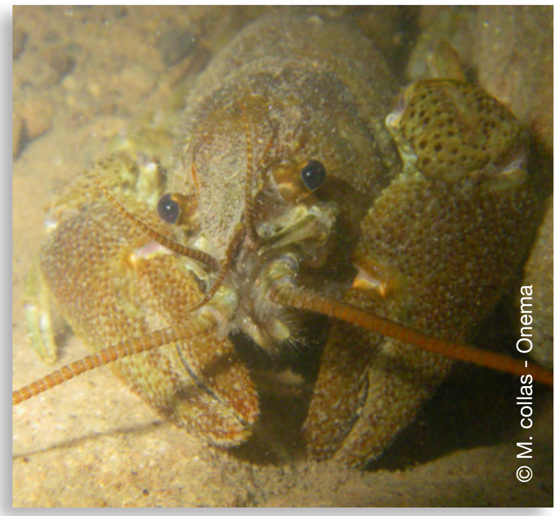
The situation is also worrisome for freshwater crustaceans, where 161 species out of 576 are threatened. Stone crayfish (Austropotamobius torrentium) are one of the critically endangered species, whereas the white-clawed crayfish (*Austropotamobius pallipes*) is classed as vulnerable. Concerning the overseas territories, areas with very rich, but fragile aquatic environments, due notably to the insular context, the situation is just as worrisome. For example, on Reunion Island, 8 fish species out of 24 are considered threatened.

These data (F. Kirchner, IUCN France), presented at the beginning of the symposium, were drawn from the Red list of threatened species published by the French IUCN committee. Prepared using the method employed worldwide by IUCN, the Red list is a prime scientific and decision-making tool informing on the risk of species extinction. The assessment process brings in scientists with expert knowledge on the taxa for specialised workshops. Classification of the species in the various categories is based on precise biological criteria, *e.g.* population numbers, decline rate, size of range and the degree of range fragmentation. In addition to this species-centred approach, IUCN has also developed for a number of years an ecosystem-classification system to provide a more integrated vision of biodiversity status (see section 2.2.).

Figure 2. Status of 69 species of freshwater fish in French continental waters according to IUCN.



White-clawed crayfish and pike were previously abundant, but have now been listed as vulnerable by IUCN.



1.2 – Positive signs in time trends

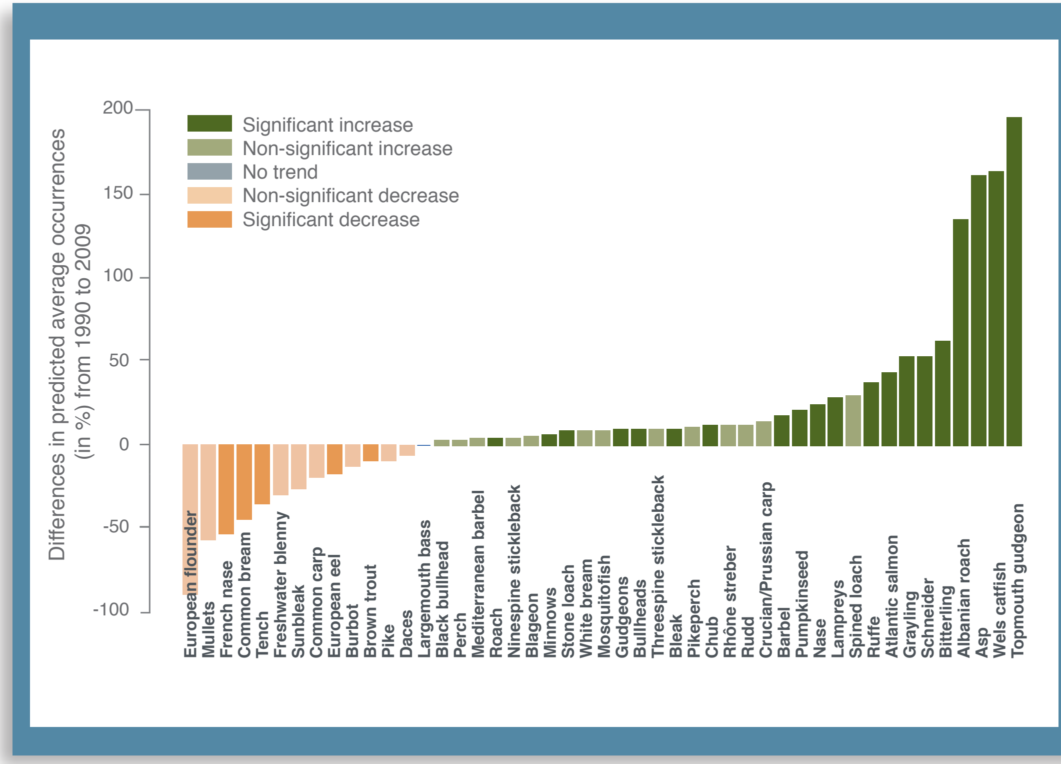
Biodiversity status at a given moment is the result of a set of complex processes. Some pressures may be removed, others may worsen, the climate may change or restoration work may be undertaken. That is why the analysis of time trends for a species, *e.g.* changes in its range or density, is extremely useful in understanding its status in dynamic terms.

This type of study covering all of continental France was carried out on fish communities. The analysis (N. Poulet, Onema) used the Onema database on fish and aquatic environments (BDMAP), which contains the results of over 11 000 fish surveys carried out since the 1970s in France. After selecting the data series comprising at least eight years of monitoring data based on an identical sampling strategy, the final data set included 7 748 sampling operations carried out on 590 monitoring points over the period 1990 to 2009. The data set spanned the entire country and water bodies of all sizes were evenly represented.

The results are fairly divergent for different species, but signal significant and rather positive changes. For example, the average species richness (the average number of fish species noted per monitoring point) rose from 8.1 to 9.5 from 1990 to 2009. At 58% of the monitoring points, more species are present now than 20 years ago. However, this trend is not evenly spread throughout the country. Rivers in North-Eastern France show significant gains in species richness, whereas in other regions, notably in Western and South-Western France, the situation is less favourable.

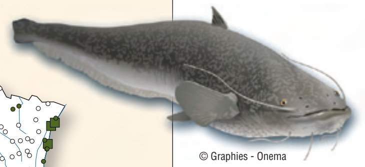
Of course, the trends vary for the different species. For 42% of the species, the average occurrence (the presence of the taxon at a monitoring point) has increased sharply since 1990. The average occurrence dropped for only 11% of species (Figure 3). Over the same period, the average density at all monitoring points also increased sharply for 74% of species, it dropped for only 17%.

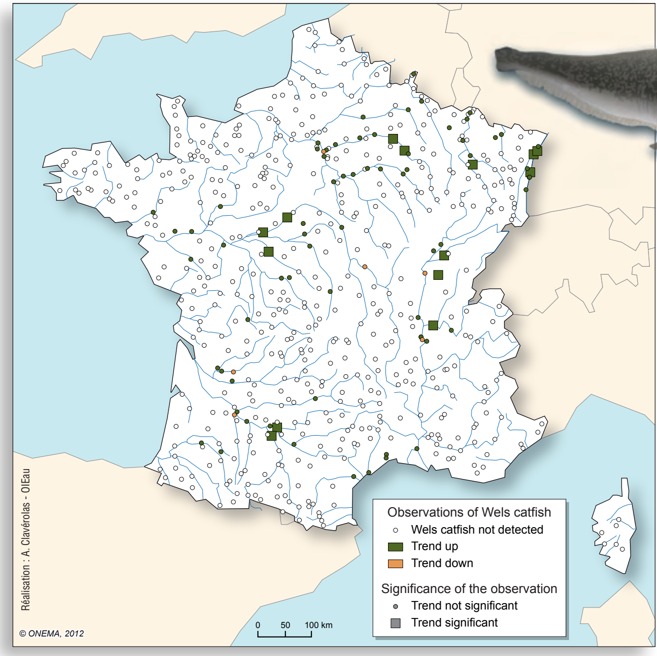
Figure 3. Change in the average occurrence (in %) from 1990 to 2009 for 47 species of freshwater fish in continental France.



The fish that increased most strongly, both in density and occurrence, were introduced species, *e.g.* Wels catfish (*Silurus glanis*) (Figure 4a), topmouth gudgeon (*Pseudorasbora parva*), mosquitofish (*Gambusia holbrooki*), asp (Aspius aspius), etc., and small species such as schneider (*Alburnoides bipunctatus*), bitterling (*Rhodeus amarus*), ruffe (*Gymnocephalus cernuus*), etc. Among the declining species are native fish, *e.g.* tench (*Tinca tinca*), bream (*Abramis brama*), eels and brown trout (*Salmo trutta*) (Figure 4b). Here again, the overall trends were not spread evenly over the entire country.

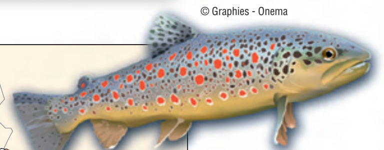
a

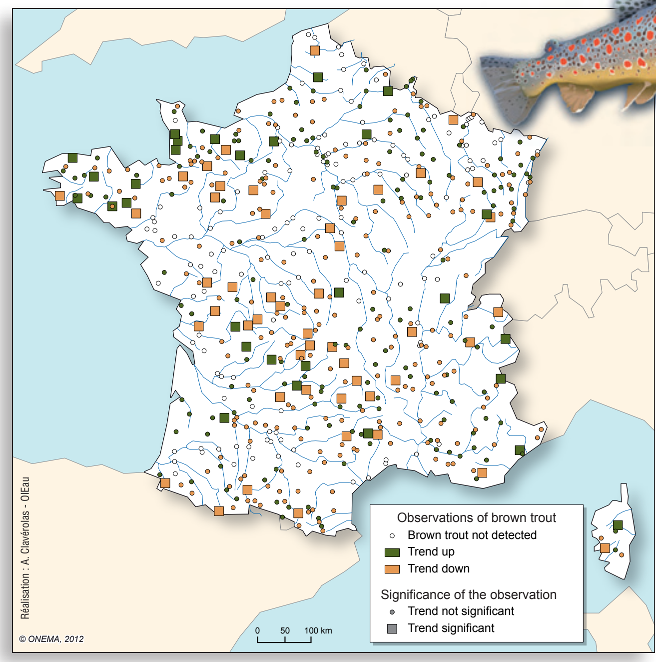




Figures 4a and 4b. Examples of trend maps for densities of Wels catfish (a) and brown trout (b).

b





What factors can explain this change?

Interpretation of these trends remains a complex process. For example, the study attempted to link the noted changes to climate change because previous research has shown that climate change, on the whole and at temperate latitudes, tends to result in increases in the total density, particularly for small species (Daufresne *et al.*, 2009) and in species richness, though more for species inhabiting temperate waters than those inhabiting colder waters.

But no clear correlation could be established between the observed trends for each species and their reproduction temperature. Adaptation mechanisms could explain certain local changes. The situation is further complicated by restocking efforts, *e.g.* for grayling (*Thymallus thymallus*), pike and brown trout. The efforts over the past 30 years to control and improve water quality, notably by reducing organic and phosphate pollution, were certainly a key factor in the improvements observed on the national level.

For the declining species, a number different hypotheses may be put forward. The case of the eel is the best documented (see section 4.3.). This migratory species was subjected simultaneously to dams blocking its movement, overfishing and damage to its habitats. For bream, the observed decline may be linked to the parallel drop in eutrophication levels in rivers. Tench have most probably suffered from the loss of side channels, one of its preferred habitats. The study results were published in an international journal (Poulet *et al.*, 2011) and may be found (in French) in the Eaufrance Briefs series (http://www.onema.fr/collection-les-syntheses-eaufrance).

The study, though very well received during the symposium, obviously suffers from certain limits at this stage in the research. In particular, it could not detect significant trends for the rarest and often the most threatened species, as the IUCN data made clear (see section 1.1.), *e.g.* weather loach or European sturgeon, for which very few data are available. In other cases, for example Atlantic salmon, the data could not be used to characterise the decline of the species because the decline started well before the study period (see the Spotlight on the contribution of historical documents in understanding biodiversity). A number of topics were proposed for further research, *e.g.* the trends must be studied on different geographic scales (catchment basins, entire rivers, etc.) and filled out where possible with historical data and better integration of the impacts of restocking.

1.3 - Useful knowledge from local monitoring

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Removal of scales on an Atlantic salmon for the long-term study on migratory salmonids in the Bresle river.

In-depth studies on a particular ecosystem or fish population, occasionally spanning decades, represent an extremely useful contribution to wider assessments and to efforts to link changes in communities to pressures or to environmental factors. Two such long-term studies were presented during the symposium and constitute the topic of this section.

Sea trout and salmon in the Bresle river, two populations closely studied for 30 years

The populations of sea trout and Atlantic salmon in the Bresle, a coastal river in the Picardie region, have been systematically studied since 1982 by Onema (previously the High council on fisheries), including population numbers, size, weight, survival rate in the ocean and the river, in connection with climate and hydrological parameters.

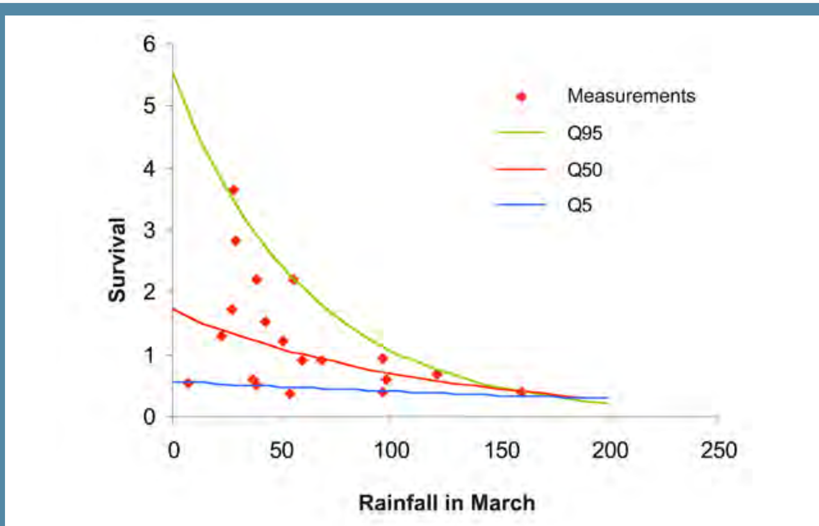
The results, presented during the symposium (Gilles Euzenat, Françoise Fournel, Onema), provide a very clear image of the local population of migratory salmonids. In the Bresle river, the two species are fairly similar, *i.e.* a short biological cycle of three to four years and similar sizes with 55 cm and 2.4 kg for trout and 66 cm and 2.9 kg for salmon. The numbers of adult trout were eleven times higher than those of salmon, *i.e.* 1 640 trout compared to 148 salmon on average over the period. In both cases, the monitoring programme revealed major changes, *i.e.* the trout population increased significantly after 1997 and the salmon population underwent a severe drop from 1993 to 2004, due to higher marine mortality, before rising back up to the initial level.

The average size of adults in both species has undergone a continuous decline. Over the 30-year period, the length of trout has dropped from 57 to 53 cm and that of salmon from 68 to 63 cm. The reasons for the drop differ. For trout, it is essentially due to a younger age structure, with the size remaining constant for a same “sea age”. For salmon, on the other hand, the drop in size corresponds to a reduced size for a given “sea age”. This drop in size and in weight represents a loss of 18% of the biomass of reproducers, all else being equal. Other changes, revealed by scientific monitoring, confirm disturbances in the dynamics of the two populations over the study period, including faster growth in the river, slower growth in the ocean, earlier maturation, increased juvenile mortality in the ocean for salmon, increased mortality post spawning for trout, clear shifts in migration periods, etc. These strong signals indicate disturbances and adjustment in the ecology of the species in reaction to changes in the environment.

Multi-year monitoring of the survival rates of the two species, in both the river and the ocean, also revealed significant changes over time and differences between the two species. An analysis of these results in light of climate change has produced a few observations. In particular, it is possible, for salmon, to draw a negative correlation between the survival rate in the river and rainfall when the alevins come out in March. The highest survival rates systematically correspond to total monthly rainfalls under 60 mm (Figure 5). It is, of course, not the rainfall itself that impacts the survival rates, but the urban and agricultural run-off that it produces, combined with the sediment load that is a negative factor for early survival. No correlation of this type has been found for trout, because the very low biological survival rate (intrinsic or caused by a reproductive potential far in excess of the available habitat) outweighs any possible environmental impact.

This information and the data on the populations of sea trout and salmon are very rare and, in some cases, unique. They constitute an important contribution to our knowledge on the two species and are of the utmost value in designing management and restoration measures, both *in situ* and for other river basins. They are the product of daily work over a long period, the only means to acquire the long-term perspective required for valid science advice and assessments, integrating both the biological and environmental aspects, and attempting to distinguish between internal and external features, between natural and anthropogenic factors. The Bresle river, with the Onema monitoring point at Eu, stands out as a reference on both the national and international levels.

Figure 5. Salmon survival rates and rainfall during alevin emergence.



Lake Geneva, an inland sea.

Lake Geneva and Lake Annecy, two closely monitored ecosystems

An in-depth monitoring system has been in operation for Lake Geneva since 1974 and was expanded to include Lake Annecy in 1986. The CIPEL (International commission for the protection of Lake Geneva) draws samples once or twice a month, measures physical-chemical parameters (temperature, pH, nitrate and phosphate concentrations, etc.) at different depths ranging from the bottom to the surface, collects phytoplankton at depths up to 50 metres and measures the chlorophyll a, samples zooplankton using nets up to 50 metres deep, identifies and counts species, etc. Fish populations have also been systematically monitored since 1986 thanks to the daily statistics of commercial fisheries stored in databases, which make it possible to monitor the population dynamics of species having commercial value.

This vast amount of data, unequalled elsewhere in France, is used for integrated analysis of the current development of the two ecosystems, their biodiversity and their individual responses to climate change, and has been the source of numerous publications. The two peri-Alpine lakes are both positioned on a limestone substratum, but have evolved differently, due notably to their vastly different sizes, *i.e.* 582 square kilometres and an average depth of 152.7 metres for Lake Geneva, compared to 27 km² and an average depth of 41.5 metres for Lake Annecy. In both lakes, summer thermal stratification is stable and neither of the two freezes in winter. The Lake Geneva environment is mesotrophic (relatively rich in nutrients), whereas Lake Annecy is more oligotrophic (poor in nutrients). With the exception of temperature rise, the most important change in Lake Geneva over the last few decades has been the concentration of phosphorous in lake waters. Eutrophication has increased sharply with total phosphorous rising from 20 µgP/L in the beginning of the 1960s to 90 µgP/L in the beginning of the 1980s (Figure 6). Since then, there has been a reverse trend toward oligotrophication following a number of political decisions, including phosphate removal in wastewater-treatment plants starting in 1973 and the banning of phosphates from washing detergents, first in Switzerland in 1987 and France in 2007. In Lake Annecy, the total phosphorous concentration has never exceeded 20 µgP/L since 1988 because protective measures were set up very early.

Figure 6. Concentration of phosphorous (P) in Lake Geneva since 1955 (WTP = wastewater-treatment plant).

The long-term monitoring of the two lakes made it possible to study the links between phosphate concentrations and changes in the respective biological communities, ranging from phytoplanktonic assemblages to fish populations. The other main factor contributing to change is temperature rise, again with clearly different situations in each of the two lakes. Lake Annecy does not have sufficient thermal inertia to register a rise in temperature caused by climate change because a cold winter suffices to "reset" its lowest winter temperature to approximately 4°C. The great depth of Lake Geneva, on the other hand, means that climate change can produce a faint signal. The average temperature five metres below the surface has risen approximately 1.5°C over the past 40 years. This temperature rise has produced significant changes in the ecosystem, *e.g.* thermal stratification earlier in the year and lower oxygen levels in the deeper waters. These phenomena have cascading impacts on all aspects of the ecosystem in Lake Geneva. An analysis of these changes (D. Gerdeaux, INRA) was presented in detail during the symposium and is the topic of the "Spotlight on Lake Geneva" at the end of chapter 3.

Protection of a reed bed in the port of Sévrier, in Lake Annecy.

In Lake Geneva, on the Bresle river and elsewhere, these (rare) long-term monitoring programmes are local observatories of aquatic biodiversity supplying precious data used to draft national status reports, gain knowledge on how aquatic biodiversity shifts in response to global change and identity the best management techniques to restore ecological balances. The continuation of these programmes is not guaranteed, however, because funding can be cut or reallocated elsewhere and the departure of a few motivated researchers can sometimes weaken an entire programme. The need to continue these programmes met with wide approval during the symposium on the part of both scientists and water managers.

Long-term monitoring of fish populations is very important for both scientists and water managers.

Spotlight

Taxonomic difficulties

In order to understand biodiversity, it is first necessary to identify, class and name the various living organisms that make up ecosystems. That is the purpose of taxonomy, which for the past 250 years has served to describe over 1.7 million species, using essentially morphological, anatomic and ethological criteria. However, taxonomy is a dynamic field of study and new tools (electronic microscopes, morphometrics and molecular genetics) have been brought into play over the past decades. A new "integrative" approach to taxonomy now attempts to distinguish taxa on the basis of five complementary aspects, namely DNA, geography, morphology, ecology and reproduction. A species is "validated" when at least two aspects are congruent.

This technique can result in significant revisions in the classification of species, an example being the work on different freshwater fish in France, namely chub, dace, gudgeon, skulpin and minnows (Gaël Denys, MNHN; Vincent Dubut, Aix-Marseille University). For example, only one species of gudgeon (*Gobio gobio*) had been identified in France (Keith & Allardi, 2001). But a study on the morphological criteria (Kottelat & Persat, 2005) indicated that there are in fact four species. Using the integrative approach, MNHN confronted the results of the morphological study with an analysis of the mitochondrial COI marker of the specimens. This molecular technique confirmed three of the proposed species and the taxonomic system now recognises *Gobio gobio, Gobio lozanoi* and *Gobio occitaniae* in France. The same approach validated two species of dace and two of chub (compared to one previously), and a total of eight species of skulpin (compared to two previously) are now in the process of being validated (Keith *et al.*, 2011).

Another surprising case is that of the minnow. Whereas first one species (Keith & Allardi 2001), then two others were described in France (Kottelat, 2007), a genetic study using various molecular markers was carried out with funding from Onema on 600 fish drawn from 28 populations in nine hydrogeographic regions. The results revealed strong genetic structuring of populations in each hydrogeographic region and very slight impact of translocation efforts. The study confirmed the nominal species described by Kottelat (2007) and also identified six other species that must still be validated by another criterion.


Gobio lozanoi


Gobio occitaniae


Gobio gobio

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2 Innovative tools

for new knowledge and management


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Thanks to the European policies, above all the WFD and the Habitats directive, a set of operational methods has been developed in France to better understand changes in aquatic biodiversity and assist in its management.

New tools have come on the scene due to technological (r)evolutions whereas others have emerged as a result of accumulated data and knowledge gained from decades of ecology research and species surveys.

This second part presents a few of those new, innovative tools, ranging from environmental DNA for river surveys to new integrated assessment techniques for biodiversity, that will enable water managers to work more effectively in the future for the preservation and restoration of aquatic environments.

2.1 – Environmental DNA for *in situ* surveys

For surveys of fauna and flora in aquatic environments, water managers currently use a number of proven methods such as netted or bottled samples of planktonic communities, sediment samples for benthic invertebrates, electrofishing for fish communities, etc. But these techniques often incur high costs in terms of the time required and personnel, and all have a number of limitations. Identification of taxa in the lab, *e.g.* for invertebrates and diatoms, is also long and costly.

The development of biocomputing and approaches based on DNA identification are very promising techniques that complement and can replace current techniques. The environmental DNA method (eDNA) presented during the symposium (C. Miaud, École pratique des hautes études) is now generating increasing interest on the part of scientists and water managers.

The basic idea is simple. After collecting an environmental sample, *e.g.* a volume of water from a river, the DNA fragments in the water are “amplified” using universal primers (plants, mammals, fish, etc.). They are then sequenced and identified using a reference dataset. In France, this method has been tested since 2011 for fish surveys in rivers. A genetic reference dataset was established (by LECA and the SPYGEN company with funding from Onema and contributions from various stakeholders including MNHN, Irstea, Conapped, Tour du Valat, etc.) after the genome of 95 fish species had been sequenced. An initial comparative study was run on six sites where both electrofishing and eDNA surveys were carried out.

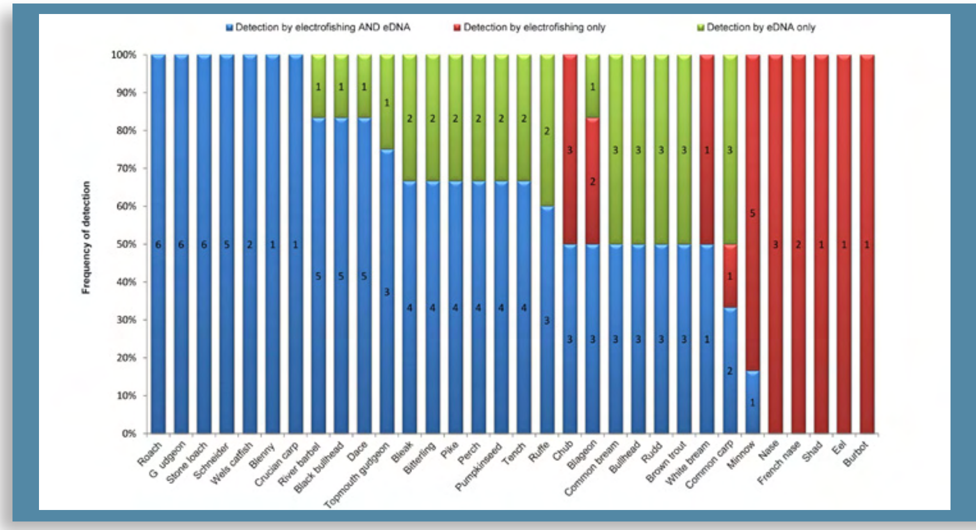
Electrofishing in the river implemented the WFD standardised protocol. For the eDNA technique, 50 litres of water were drawn from each site. A total of 31 species were detected by electrofishing, compared to 26 for the eDNA technique (Figure 8).

Water is pumped, then filtered to obtain fish cells containing DNA.

More or less serious discrepancies were noted between the sites and certain species were occasionally detected by only one technique. These differences may be caused by a number of difficulties. In those cases where the eDNA technique did not detect a species whose presence was confirmed by electrofishing, the problem may be due to the sample (the DNA of the species was not contained in the water sample), faulty amplification of the DNA fragment by the primers or an error in the reference dataset. In those cases where electrofishing did not detect a species whose presence was signalled by the eDNA technique, there are a number of hypotheses to explain the differences:

- the DNA signal was not meaningful (*i.e.* it may be considered background noise) and the species should not be considered present;
- the species may have been present on the site, but was not caught (rare species, notably when the fishing campaign was not complete);
- the species may be present on the site only during certain periods (several weeks passed between the electrofishing and the samples taken from the water);
- the species may be present upstream of the site (the DNA fragments may continue to be detectable for a certain time in the river current).

Figure 8. Frequency of detection for each species by eDNA and/or electrofishing.



These initial results confirm the value of the eDNA technique as a complement to electrofishing (though eDNA does not inform on the size structure of a population, nor does it provide estimates on abundance and biomass), particularly for large rivers. It can also inventory several aquatic communities with a single sample, *i.e.* potentially amphibians, aquatic mammals, invertebrates, etc. However, the technique must still be improved prior to routine use, *e.g.* in monitoring networks. The goal of establishing a reliable link between the DNA identified in a sample and the biomass of a species in a given water body has still not been achieved... for the time being. The research teams are working on setting the interpretation thresholds and optimising the analysis methods for the signal, all of which should make it possible to better determine the detection distances for each species. Further progress may be made by developing more integrative sampling systems, for example by using larger sample volumes in order to improve detection of rare species and those with low population densities. All the above points will become the topics of research projects funded by Onema in its partnership with LECA, SPYGEN and Irstea.

2.2 – An integrated approach to biodiversity for monitoring and assessment

Knowledge of the number and density of species present is not sufficient to determine the biodiversity of a territory. Biodiversity traditionally comprises three aspects, the specific diversity, the genetic diversity of a given species and the diversity of the ecosystems in the territory. In addition to the approaches based on faunistic and floristic surveys, the development of tools offering an integrated approach to biodiversity has over the last few years become a fundamental trend underlying current assessment strategies.

IUCN ecosystem assessment

In 2008, IUCN launched a project to develop a method to establish, in parallel with its Red list of threatened species, a Red list of ecosystems. Following a number of workshops in 2011 to define the criteria for an ecosystem assessment, the innovative approach was presented to the World conservation congress held in Jeju, South Korea, in 2012. Eight categories were created for ecosystems, based on the existing categories for species, namely collapse (CO), critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT), least concern (LC), data deficient (DD), not evaluated (NE). The status of an ecosystem is determined by the worst result for any of the five criteria, *i.e.* a reduction in the geographic distribution (A), a restricted geographic distribution (B), abiotic environmental degradation (C), disruption of biotic processes or interaction (D) and quantitative analysis on the probability of collapse (E). The result for each criterion is produced by a precise analytical procedure. For example, the criterion concerning a reduction in the geographic distribution comprises reductions since 1750, those having occurred over the past 50 years and those expected over the next 50 years.

In France, the first case studies, presented during the symposium (A. Carré, IUCN France), were carried out on Mediterranean lagoons,

Lake Sanguinet in the Landes department in France is considered "endangered" by IUCN.

lakes and ponds along the Aquitaine coast, the intertidal zone of the Atlantic marshes and the Arcachon basin. The latter, for example, was classed "vulnerable" due to the results for criterion C (contamination and eutrophication caused by concentrations of heavy metals, PAHs and pesticides) and criterion D (decline of zostera seagrass, a key ecosystem species). The lakes and ponds along the Aquitaine coast are seen as "endangered" given the rapid development of invasive plants (criterion D).

This integrative system provides a reference framework to monitor the biodiversity of ecosystems and will be progressively deployed worldwide by IUCN, similar to the assessment system for species. The ecosystem Red list, like the species Red list, provides managers with a valuable operational tool in that the assessment pinpoints the most threatened ecosystems and the pressures requiring priority corrective measures. It thus contributes to guiding and supporting policy and management strategy in the effort to conserve and restore biodiversity.

The decomposition rate of leaf litter informs on the operation of an ecosystem.

Development of indicators on ecosystem operation

The operation of aquatic environments is the product of a very large number of interactions between living communities and between those communities and their abiotic environment. This complexity makes routine and reliable assessment of environments difficult and expensive, for example in the framework of the regular monitoring programmes required to determine the ecological development of restored ecosystems. A great deal of work is currently being put into the development of "functional" assessment tools capable of integrating the complexity by measuring a simple signal that informs on the operation (good or bad) of the fundamental interactions within an environment.

In France, the development of these assessment tools has been undertaken by a partnership managed notably by Onema. A set of six research projects has been launched for the period 2012 to 2015. The goal of the first is to develop an assessment tool based on the measurement of indispensable ecological processes such as recycling of organic matter and the elimination of nutrients, in order to assess the ecological quality of rivers and monitor their restoration (J.-M. Baudouin, Onema, G. Tixier, Metz University). The first of the tested protocols monitored the decomposition kinetics of particulate organic matter. An effective solution consisted of using cotton strips as a standardised substratum. The value selected to quantify their decomposition as a function of the exposure time is the loss of tensile strength (Tiegs *et al.*, 2007). The system was tested in 2012 on six rivers in the Lorraine region, with exposure times of 10 and 32 days. The initial results reveal drastic alterations in the recycling processes of organic matter, for equal exposure times in the water, depending on the anthropogenic pressures weighing on the rivers (intensive agriculture, modification of the river bed, urban development along the banks, etc.).

The other research projects underway are exploring different solutions to monitor the effectiveness of restoration work, ranging from the standardisation of methods to monitor the decomposition of leaf litter to isotopic methods to assess the status of food webs and the development of indicators for the self-cleaning capacity of river sediment.

The European pond turtle (Emys orbicularis) *is a species protected by national (ordinance dated 19 November 2007) and European (Annexes II and IV of the Habitats directive) regulations.*

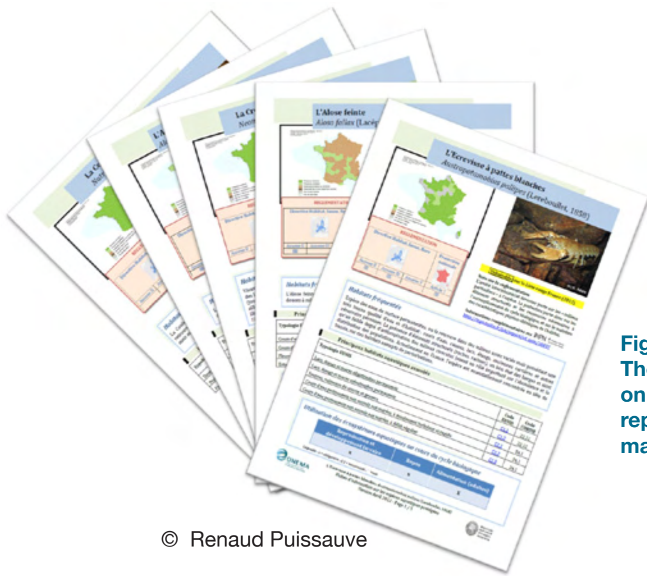
These tools may provide the ideal complement to "standard" indicators (*e.g.* bioassessment tools based on the composition of a given biological community), by refocusing analysis on ecosystem operation.They are also capable of rapidly detecting ecosystem response to the elimination of a pressure (in which case they are called a leading indicator). These techniques are suitable for standardised monitoring methods and also produce relevant data for economic assessments and the numerical analysis of ecosystem services. Finally, these assessment tools can assist in quantifying ecological functions, key factors in efforts to compensate environmental impacts.

2.3 - Practical data sheets for managers of protected aquatic species

The European Birds directive (1979) and the Habitats directive (1992), key elements in EU biodiversity policy, created the objective for the Member States of "maintaining or restoring favourable conservation status" of important plant and animal species listed in Annex II.

In France, these regulations were transposed to the Environmental code, notably article L.411-1 which stipulates that all harm to animals protected nationally is forbidden, including the destruction or removal of eggs or nests, mutilation, killing, capture or removal from their environment, intentional disturbances, taxidermy, etc. Depending on the species, this protection also applies to their "particular environments", including rest and reproduction zones and corridors for movement. These restrictions apply as long as the particular environments can be used during the rest and reproduction cycles of the species and in all cases where any alterations caused by a project may hinder the "effective functioning of the biological cycles of the species". If a particular project so requires, exemptions under certain conditions are possible, however measures to compensate or mitigate the effects must be undertaken.

For local stakeholders and the authorities evaluating a project, implementation of this protection policy and particularly decisions on exemption requests are often very difficult. Numerous questions arise, *e.g.* what are the particular environments of a species? What is the conservation status of the populations concerned by a project and how can it be assessed? How does the project affect the various phases of the biological cycles? Etc. To assist the local stakeholders, the Ecology ministry, Onema and the National museum of natural history (V. de Billy, Onema, R. Puissauve, MNHN) initiated in 2011 a series of data sheets summing up the scientific knowledge available on 105 protected species dependent on aquatic environments (Figure 9).

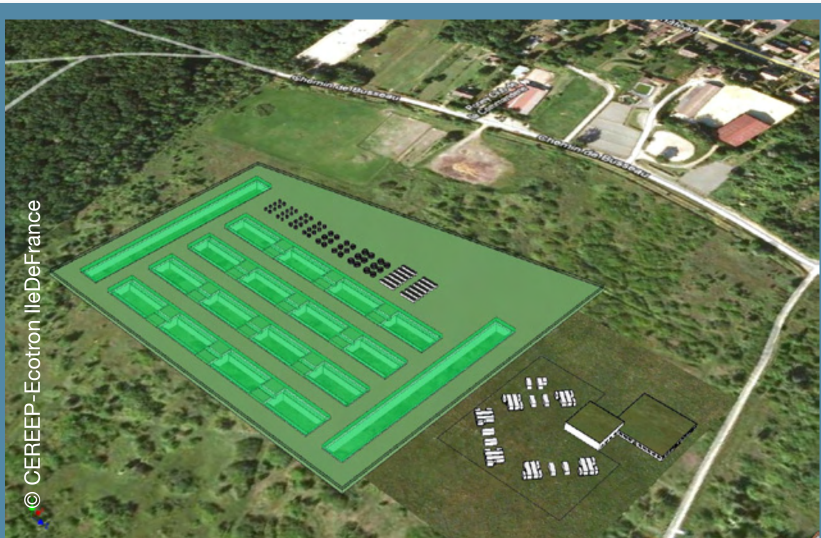


© Renaud Puissauve

Figure 9.
The data sheets on protected species represent an important management tool.

Designed as true management tools using a standardised format, the data sheets provide all the information required to implement the protection measures for a species, including its distribution in France, regulatory status, conservation status as per IUCN, a description of its particular habitats (with typological equivalences), information on biological and physical-chemical aspects, feeding, reproduction periods, phenology, etc. Each data sheet also suggests ways to avoid or reduce the impact of various types of project on the species. They are drafted by MNHN (R. Puissauve), then validated by experts for each species. The data sheets, well received by numerous managers at the symposium, represent a long-term project. Following the drafting of six sheets in 2011 and 25 in 2012, another 20 are being prepared for 2013. They may be found on-line on the Onema site (http://www.onema.fr/Especes-aquatiquesprotegees) and on the INPN site (http://inpn.mnhn.fr/actualites/lire/1781/mise-en-ligne-de-fiches-de-synthese-sur-les-especes-aquatiques-protegees).

Figure 10. Drawing of the planned PLANAQUA platform with its artificial lakes and mesocosms on the CEREEP-Ecotron Île-de-France site (image not contractually binding).



Spotlight

Using mesocosms to understand aquatic biodiversity

In a context of global change, an *in situ* understanding of the mechanisms governing aquatic biodiversity constitutes a true scientific challenge due to the complexity of ecosystems. Mesocosms, used to complement knowledge acquired in the field, are a useful experimental approach for researchers and managers. Defined as "artificial systems placed in natural environmental conditions and that are sufficiently complex and stable to achieve self-sustaining status" (Caquet *et al.* 1996), they have been used since the 1970s in the fields of ecology and ecotoxicology. Their volume generally varies from a few hundred litres to a few hundred cubic metres and experiments range from several weeks to months. Occupying a position between laboratory systems and natural ecosystems, mesocosms can simultaneously address different food-chain levels and offer the possibility of drawing samples from a given population over time, of replicating treatments and of creating complex factorial experiments. On the other hand, problems may include a low signal-to-noise ratio and limited ecological realism. Depending on the situation at hand, their implementation must target the best compromise between mesocosm size and number. In 2010, Onema published in the Meeting Recap series a booklet on the topic titled "Mesocosms. Their value as tools for managing the quality of aquatic environments". The value of having a number of larger (several hundred cubic metres) experimental systems was highlighted during the symposium (G. Lacroix, CNRS). Because they better represent the spatial complexity of natural environments and can contain complex ecological communities, mesocosms enable more direct links between the fundamental questions raised by scientists and social demands concerning environmental management and water quality. In France, the PLANAQUA platform will soon provide scientists and managers with a set of experimental systems of various sizes (Figure 10). The project, thanks to funding from the Equipex programme in 2011, is now being set up on the CEREEP – Ecotron Île-de-France site (http://www.foljuif.ens.fr). By 2014/2015, it will offer microcosms and bioreactors ranging from a few decilitres to a dozen litres for experiments on microbial and planktonic communities, mesocosms ranging from a few cubic metres to dozens of cubic metres with significant means to control thermal gradients and water mixes, and finally a set of 16 artificial lakes (also called macrocosms), each containing 700 cubic metres and well equipped for the study of complex communities, even including carnivorous fish at the top of the food chain.

3 Climate-change impacts and adaptation

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In France, the average air temperature has increased by approximately 1°C since 1910. It is now certain (Fourth IPCC assessment report, 2007) that the main cause of the disturbances in the climate system noted on the global scale is the increase in atmospheric concentrations of greenhouse gases resulting from human activities. It is also acknowledged that climate change will continue and intensify over this century to a degree that will depend on the future anthropogenic emissions of greenhouse gasses. In France, considerable effort has been put into the study of present and future impacts on aquatic environments, notably via the GICC programme (climate-change impacts and management) set up by the Ecology ministry and Onema.

The results of some of the work were presented briefly in the booklet titled "Climate change. Impacts on aquatic environments and consequences for management", published in 2010 in the Meeting Recap series (http://www.onema.fr/collection-les-rencontres-syntheses). The 2012 symposium on aquatic biodiversity was an occasion to present a number of other studies which are the topic of this third part.

3.1 – Visible impacts on fish populations?

Climate change represents an increasingly serious disturbance for aquatic environments. From 1978 to 2008, the temperature of the entire section of the Rhône River in France rose between 1 and 2°C. In the mid-section of the Loire River, temperature rise of 1.5 to 2°C was recorded between 1977 and 2003 (Moatar & Gailhard, 2006).

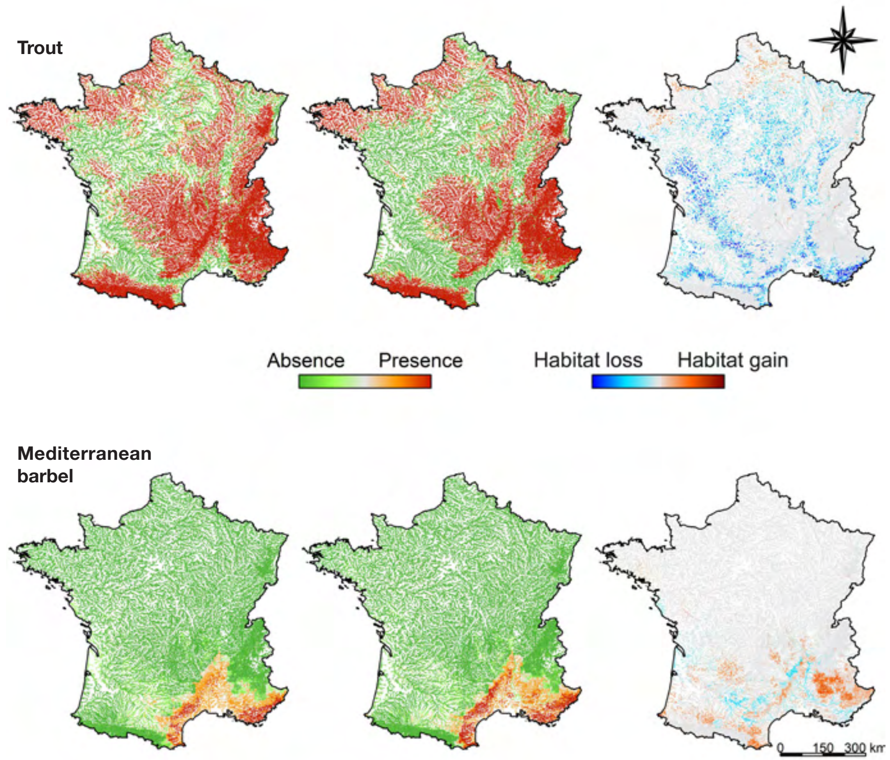
Confronted with these changes, plant and animal species tend to adopt two types of response, *i.e.* geographic transfers to remain in their climatic niche and/or adaptation to the new, local conditions. Numerous taxonomic groups have recently been observed to move, namely plants (Lenoir *et al.*, 2008), birds (Thomas & Lenon, 1999), insects (Wilson *et al.*, 2005) and small mammals (Moritz *et al.*, 2008). For fish, a number of models foresee significant changes in distribution ranges by the year 2100 (see section 3.2.).

But are such changes already visible? A study (L. Comte, Toulouse University III) attempted to answer that question for continental France, using the data since 1980 in the BD-MAP database managed by Onema (see section 1.2.). Analysis of the meteorological data covering the three decades revealed two periods, a "cold" period from 1980 to 1992 and a "warm" one from 2003 to 2009. Between the two periods, the temperature rise of the air at a given monitoring point was 0.74°C on average. The increase was not identical for the entire country, however a vast majority of monitoring points recorded a significant increase in temperature. The next step was to model the changes in the distribution of 32 freshwater fish species in terms of their presence or absence, between the two periods, based on fish surveys run on rivers throughout France. The selected database included surveys on over 3 500 sites during both periods. The comparison of the distribution ranges produced maps of the distribution of each species.

The recent regression of brown trout (Salmo trutta) may be due to climate change, among other reasons.

The results revealed major differences between species. For example, brown trout are disappearing from the edges of their initial distribution zone, whereas Mediterranean barbel are increasingly found along the edges of their zone. As for minnows, they have gained habitats within their initial distribution zone.

Figure 11. Examples of maps showing the changes in distribution for brown trout and Mediterranean barbel. On the left, favourable habitats during the "cold" period (1980 to 1992). In the middle, favourable habitats during the "warm" period (2003 to 2009). On the right, the difference between the two. The red colour indicates a habitat gain, the blue colour a habitat loss.



In a general context of global change, these observations cannot, of course, be attributed to temperature rise alone. However, an analysis of species distribution along the altitude gradient remains a useful criterion for the study of responses to climate change. The study revealed that most species are now present at higher altitudes. The increase is 1.37 metres per year on average, *i.e.* a rate far higher than the average for other taxonomic groups (+ 0.61 metres per year, according to Parmesan & Yohe, 2003). This increase in altitude for fish species would however not appear to be sufficiently rapid to compensate for temperature rise and thus enable the fish to maintain their climatic niche. This observation may be tempered by taking into account the fact that species tend to “follow” their climatic niche, *i.e.* their response is delayed to some degree, but they are subjected to less temperature rise than if they had remained in their initial distribution.

Though imperfect, notably because it is based on a hypothesis conflating temperature rise in air and water, this study produced valuable data for subsequent, more in-depth analysis on the responses of each species. What are the decisive biological and functional factors determining those responses? To what extent are the shifts in the climatic niche accompanied by changes in strategies concerning reproduction, feeding and size? More generally, what may we deduce concerning the capacity of species to succeed in confronting climate change in the future? Some initial answers are provided for diadromous fish in the next section.

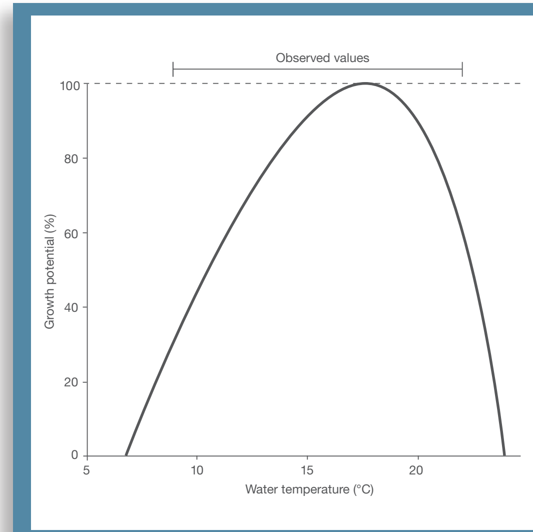
3.2 – Modelling and projections for diadromous fish

Similar to all poikotherm (cold blooded) animals, temperature influences most of the biological processes of fish (see Ficke *et al.*, 2007), as well as their life histories and traits (see Bryant, 2009), notably their energy balance, survival rate of spawn and juveniles, growth curve, sexual maturity, etc. For example, in common shad (Alosa sapidissima), the number of reproductions per life cycle increases significantly in rivers located farther to the north (Limburg *et al.*, 2003). The growth of juvenile Atlantic salmon is highly dependent on temperature and follows a bell curve (Figure 12).

Un nombre croissant de travaux scientifiques vise depuis plusieurs décennies à prévoir les implications futures du changement climatique sur la biologie des poissons et leurs populations, en lien avec le développement des outils de modélisation numérique.

A growing amount of scientific work has attempted over the past decades, in step with the development of digital modelling, to predict the future consequences of climate change for fish populations and their biology.

Figure 12. Effect of water temperature on the daily growth of juvenile Atlantic salmon (*Salmo salar*) (Bal *et al.*, 2011, adapted from Mallet *et al.*, 1999).



Diadromous (migratory) fish are particularly affected by global change, to the point of near extinction in France for several species (see section 1.1.), and have received special attention. During the symposium, one presentation (E. Rochard, Th. Rougier, Irstea) addressed recent research projects in France attempting to predict possible changes in their distribution ranges and the viability of populations between now and the year 2100 in 196 European river basins.

This work implemented two coupled approaches, *i.e.* large-scale modelling of the bioclimatic envelopes (Lassalle *et al.*, Irstea) and statistical assessment of the viability of populations over different geographic scales (Rougier *et al.*, Irstea). The database initially contained the geographic and climatic characteristics of the 196 river basins studied, plus historical data on the presence/absence and abundance of 20 migratory species in each basin since 1900. The models were run for the four sets of IPCC climate scenarios.

The results diverge significantly for the different scenarios and the species studied. Under the greenhouse-gas emission scenario A1Fi (the most pessimistic), salmon would disappear by 2100 from the Garonne and Adour river basins, from the small basins in Brittany and Normandy, and from the Iberian peninsula and most of the river basins along the Baltic Sea. Under scenario B1 (the most favourable), the species would remain present in the Garonne river basin and in most of the rivers in Brittany. The outlook is completely different for the thinlip mullet which would remain in all its current habitats in 2100, whatever the scenario, and would spread to numerous river basins in Northern Europe. The similarities and differences between the projections for the various climatic scenarios can be mapped for each river basin.

These statistical approaches are, of course, subject to certain limitations and should be seen strictly as large-scale projections complementing other sources of information. In particular, they do not take into account the population dynamics of species or the processes and obstacles that reduce their capacity to disperse. A thesis (Thibaud Rougier, Irstea) is currently underway to integrate these processes in the models.

Climate change is an additional threat to the survival of salmon populations in some river basins in France.

However, the presented results nonetheless constitute useful data for managers. Decisions and investments to save a given species must be based on the available information concerning the long-term viability of the populations in the given river basin. That being said, solutions do exist to mitigate the impacts of climate change on migratory fish and, more generally, on freshwater fish. The development of riparian vegetation, the elimination of weirs and dams, even the use of high dams to reduce water temperatures downstream (Yates *et al.*, 2008) all modify on the local level the relationship between air and water temperature. Improved connectivity between water bodies provides species with more possibilities to adjust their distribution ranges. Among other ideas, assisted migration, *e.g.* for Chinook salmon (Holsman *et al.*, 2012), has elicited very divergent reactions within the scientific community.

3.3 - How will microbial processes react to temperature rise?

Current approaches to aquatic biodiversity often focus on fish communities, macrophytes or invertebrates, the emblematic taxa most often monitored, and pay little attention to microbial communities. That is not a good idea, given their important role in the mechanisms governing natural environments.

Microbial communities are a source of vital functional diversity for the physical-chemical balance of ecosystems in that they are present at each step in the coupled carbon, phosphorous and nitrogen cycles. In a context of climate change, the study of the effects of temperature rise in water on microbial ecosystems is an important research topic in view of understanding and anticipating on the future impacts that will affect all aquatic biodiversity. Mathematical approaches and lab analyses are clearly advantageous in terms of control and replication, however they do not take into account the complexity of interactions between microscopic organisms. Mesocosms (see the Spotlight at the end of the previous chapter) offer a worthwhile compromise between replication and ecological realism. But only experimental *in situ* studies can bring into play all the parameters influencing natural microbial communities.

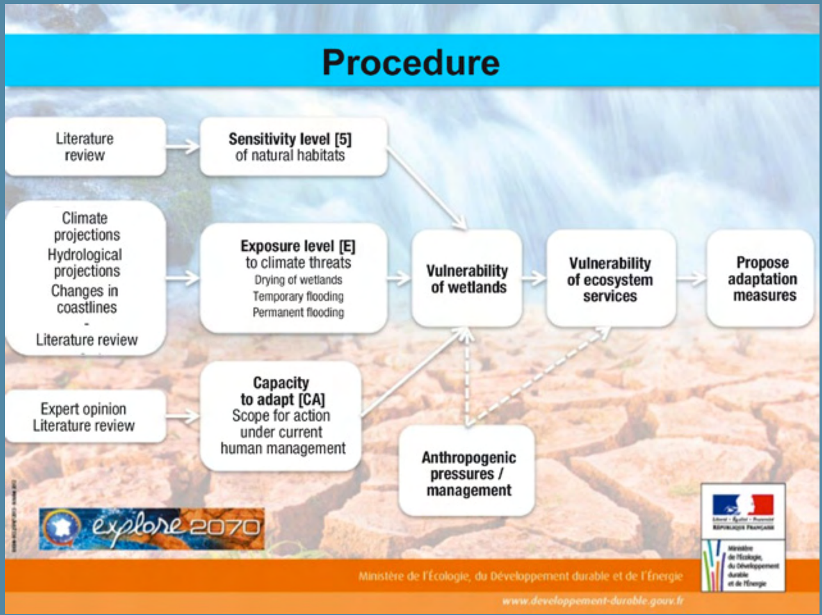
This approach was implemented (S. Boulêtreau, Ecolab, CNRS) for epilithic biofilms (biofilms on rocks) in the Garonne river at Golfech. Lying at the interface between the water column and the substratum, these biofilms represent a high density and variety of living species, including over 100 species of ciliate eukaryotes, over 75 species of rotifer eukaryotes and over 50 species of diatoms. Each gram of organic matter also contains approximately 1 011 bacterial cells. The *in situ* study consisted of comparing the structural changes in denitrifying bacterial communities, between those in the natural environment (average temperature 17°C) and those in an artificial situation of temperature rise (average temperature 19.5°C) created a few dozen meters downstream by the Golfech nuclear plant. All other environmental parameters (water depth, flow velocity, physical-chemical aspects) were identical. The incubation time was three weeks. In parallel, lab measurements were carried out, under controlled temperature conditions (1°C, 12°C, 21°C, 31°C), to quantify the denitrifying activity, respiration and primary production of different microbial-community structures. Extrapolation of the *in situ* results produced numerical data used to characterise the temperature dependence of biofilm metabolisms. After three weeks, the 2.5°C rise in temperature resulted in an increase in denitrification by a factor of 1.5. The respiration and primary production of the communities also increased, but to a lesser degree. To date, this innovative research has produced more questions than answers. On what factors does the thermal sensitivity of the denitrifying communities depend? Is it determined by their thermal history, their composition, their biomass? To what degree are the micro-organisms selected by temperature rise? What will be the temporal consequences (seasonal, annual) for nitrogen flows between biofilms and water bodies? And what will be the effects of these changes on the food web and on ecosystem services? A new study, co-financed by Onema and EDF, has been launched to answer some of these questions.

As primary producers, biofilms constitute an essential link in the operation of rivers, which is why it is crucial to understand how they react to global warming.

3.4 - Vulnerability and adaptability of wetlands

Wetland ecosystems have remarkable biodiversity, but are particularly vulnerable to climate change. The Ramsar international convention for their conservation was signed in 1972 and ratified by France in 1986. It calls on the contracting parties "to manage wetlands wisely to reduce the multiple pressures they face and thereby increase their resilience to climate change" (resolution X.24, article 28, 2002). In France, the Wetlands action plan (2010) confirmed the urgent need to set up long-term monitoring programmes to assess their evolution with respect to climate change. One of the first research projects on this topic was carried out as part of the Explore 2070 prospective-study programme. Launched by the Ecology ministry in 2010, the objective of the programme is to devise strategies to adapt to the changes in hydrosystems and coastal environments that are projected for the period 2050-2070. Among other results, a method was developed to assess the vulnerability of wetlands and the provided services to climate change. The assessment data for 11 wetlands in continental France were presented (F. Baptist, Biotope) during the symposium. For five of them, the Brenne nature park, the Bassée river valley, the Dombes and the Mauguio and Thau Mediterranean lagoons, an assessment of the ecosystem services was also carried out. The procedure is shown in Figure 13.

Figure 13. Method to assess the vulnerability of wetlands used for the Explore 2070 programme.



This procedure first requires identification of the main factors of sensitivity in a given wetland via either expert opinion or a literature review. For example, among wetlands located in inland plains, the environments most sensitive to climate change are stands of common alder and ash, bogs with white beaksedge (Rhynchospora alba), wet heathlands, meadows with moor grass, peaty environments and wet meadows with tall grasses.

During the study, three wetlands of the above types (Brenne, Sologne, Dombes) were assigned high sensitivity (S) levels. However, the analysis of exposure levels (E), integrating the expected decrease in the average precipitation and discharge levels, revealed differences with a high exposure level for the Dombes, but much lower levels for the Brenne and Sologne. Finally, the vulnerability (V) of the three wetlands is due primarily to a reduction in water depths, increased eutrophication

Wet heathlands (the Pinail area in the Vienne department in the photo) are particularly sensitive to climate change.

and the threats raised by invasive species. In the Dombes, a further vulnerability is caused by the increased risks of low flows downstream of the ponds. In the final analysis, the Dombes were considered highly vulnerable to climate change and the two other wetlands were seen as moderately vulnerable.

For wetlands in alluvial valleys, the same study method produced very different results, namely low vulnerability for the Rhin-Ried-Bruch valley, moderate vulnerability for the Bassée valley and high vulnerability for the Barthes marshes along the Adour river. The lagoons along the Mediterranean coast also produced diverse results. All the results are available on the internet at http://www.developpement-durable.gouv.fr/-Explore-2070-.html.

This approach, despite high levels of uncertainty, produces useful qualitative results enabling managers to foresee weaknesses in these ecosystems and adapt their management decisions. Work was also carried out to quantify the corresponding ecosystem services. Though incomplete, the results constitute the initial data points for an analysis of wetland ecosystem services from the economic point of view.

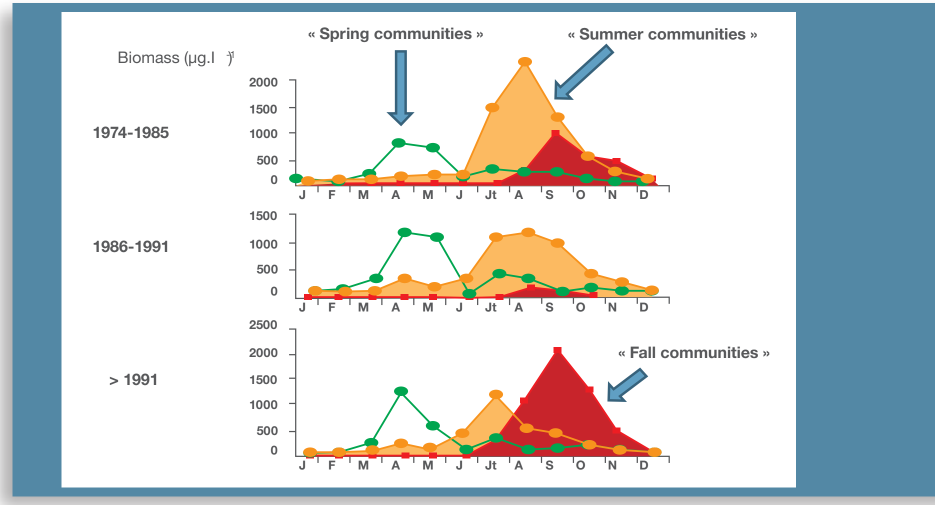
Spotlight

Lake Geneva and Lake Annecy, two closely monitored ecosystems

The very complete monitoring programme carried out on Lake Geneva since 1974 (see section 1.3.) made it possible to undertake a general analysis of the effects of climate change on all the food webs in the ecosystem. Due to its size and depth, Lake Geneva has sufficient thermal inertia to "register" climate change and the average temperature five metres below the surface has risen 1.5°C over the past 40 years. This temperature rise has modified the thermal structure of the lake. Stratification occurs earlier in the year, around 15 May in recent years compared to a month later in the 1970s. This results in less mixing of water layers and consequently in a drop in oxygen levels in the lower layers. The other major change has to do with phosphate concentrations. Following significant eutrophication between 1960 and 1975, there has been a reverse trend toward oligotrophication thanks to phosphate removal in wastewater-treatment plants and the banning of phosphates from washing detergents, first in Switzerland, then in France. During the symposium, a presentation (D. Gerdeaux, INRA) described how these two coupled parameters (climate change and oligotrophication) influence all the food webs in the lake, from phytoplankton to fish communities. Temporal modifications were observed in successive planktonic assemblages, as shown in Figure 14.

The changes in planktonic assemblages, a true biological pump for the lake, have a cascading effect on its entire biodiversity. They result in better trophic adjustment for whitefish larvae (Coregonus lavaretus), which also benefit from less competition from other species such as perch and roach. These modifications, amplified by stocking and improved water quality, are the driving force behind the population growth of the species, confirmed by the increase in annual catches which rose from approximately 50 tons in the 1980s to almost 400 tons today. The whitefish would appear to have benefited from climate change, but the same cannot be said for another flagship species in the lake, namely the Arctic charr (Salvelinus alpinus). This fish requires very cold water and has suffered from the temperature rise in the deep waters of the lake. Annual catches have fallen severely over the past decade. It is not certain that the species will still be present in the lake in 2070.

Figure 14. Changes in the successive annual planktonic assemblages in Lake Geneva, due to climate change and a reverse trend toward oligotrophication.



Catches of whitefish (Coregonus lavaretus) *in Lake Geneva have risen, but those of the Arctic charr* (Salvelinus alpinus) *have fallen sharply because the species is severely impacted by climate change.*

4 Consequences of habitat degradation and solutions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Above and beyond climatic conditions, the pressures exerted on aquatic habitats by human activities (pollution, artificial and uniform environments, abstractions, hydroelectric installations, etc.) directly impact fauna and flora. There is no lack of examples. For example, the creation of weirs and dams contributes to temperature rise in water and restricts movement of species, particularly migratory species. Containment of rivers results in the loss of flooded meadows which are the site for winter spawning of pike, among other species. The draining of side channels deprives numerous species of fish, amphibians and invertebrates of their preferred habitats. Yet it is the variety and high quality of natural habitats that determines the level of aquatic biodiversity. That is why the WFD (Water framework directive) established hydromorphology, *i.e.* the physical characteristics of the landforms containing aquatic environments, as in integral part of its programme to assess the status of water bodies. Hydromorphological concepts are now based on solid scientific knowledge and recent monitoring data from restoration projects.

Following a short section on chemical pressures, a major topic addressed by a national symposium in 2013 and the upcoming Meeting Recap document, this fourth chapter is devoted to the consequences of physical degradation of habitats for aquatic biodiversity. It briefly presents recent research in France on the links between hydrology and aquatic biodiversity, and on the impact of weirs and dams on the biology of fish species. Finally, it discusses the management plans implemented for two species particularly hard hit by hydromorphological pressures, namely the Rhône streber and the European eel.

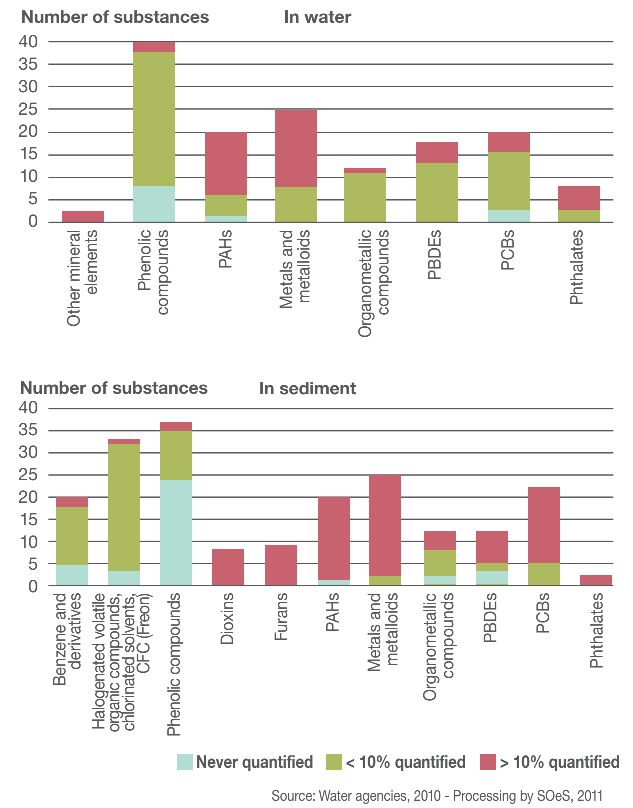
4.1 – Aquatic biodiversity requires high-quality water

Similar to the creation of artificial river banks, abstractions and fragmentation of rivers by various structures, the presence of agricultural and industrial pollutants in freshwater results in significant degradation of many aquatic habitats often with dramatic consequences for biodiversity. Acute cases of pollution, which led in the 1970s and 1980s to spectacular levels of mortality in rivers, have become rare occurrences in France, however nonpoint-source pollution of surface water bodies has remained at very high levels.

For its "Report on micropollutants in continental aquatic environments" published in 2009, the General commission for sustainable development spent two years collecting data on almost 950 different substances having proven toxic effects, even at very low concentrations, including pesticides, metals and metalloids, hydrocarbons, polychlorinated biphenyls (PCB), polybrominated diphenyl ethers (PBDE), halogenated and/or volatile organic compounds, dioxins and furans, phthalates, etc. The results showed virtually systematic contamination of aquatic environments in France. Pesticides were detected in 91% of the monitoring points on French rivers and 21% showed total pesticide concentrations higher than 0.5 µg/litre. In addition to pesticides, 22 groups of micropollutants in water and 20 in sediment were detected in continental France. Among the 17 most actively monitored groups, substances from 8 groups for water and 11 for sediment were quantified in over 10% of the samples analysed (Figure 15).

The fate of these pollutants in aquatic environments, their transfer to food webs and their impact on biodiversity are essential topics for research. In June 2013, Onema devoted a national symposium to the issue and a report will soon be published in the Meeting Recap series. Two scientific presentations on chemical pressures were also made to the symposium on aquatic biodiversity and constitute the topic of this section.

Figure 15. Number of substances quantified in over 10% of the samples analysed, by group of micropollutants not including pesticides, in rivers in continental France.



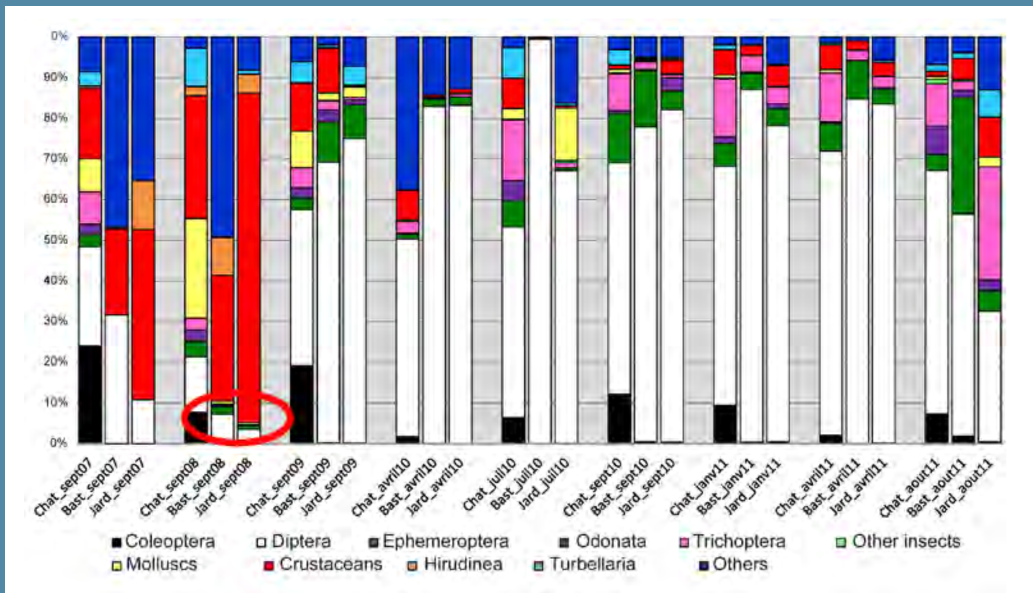
Response of biodiversity to the elimination of a chemical pressure in the Vistre River

How do biological communities respond to an improvement in the chemical status of water? Some answers were provided by a case study (V. Archaimbault and E. Arce, Irstea) on benthic invertebrates in the Vistre River (Gard department). This small river, heavily channelised since the 1600s, suffers from poor chemical status due to the discharges from a dozen wastewater-treatment plants (WTP). To reduce the quantities of nitrogen and phosphorus entering the Vistre, a new WTP started operations in 2007 to treat the sewage of the city of Nîmes. It releases the treated water one kilometre downstream of the outlet of the old Nîmes WTP that was closed in 2007.

The study was carried out from 2007 to 2011 on three sites, namely Château, located upstream of the outlets and serving as a control site, Bastide, located downstream of the old outlet, and Jardins, located downstream of the new WTP outlet. Physical-chemical measurements were run every three months at the three monitoring points. Samples of fauna were also drawn according to the XP-T 90 333 protocol at the three monitoring points.

The creation of the new WTP downstream resulted in clear and rapid improvement in the chemical quality of the water. In just a few months, the chemical parameters (notably ammonium, total phosphorous, nitrites and nitrates) returned to levels comparable to those in the upstream section. The response of the benthic communities was also very clear in terms of their abundance, richness and diversity. The populations recovered rapidly, but not to the level of the control point, which would suggest that the complete recovery of a community following the elimination of a pressure may take longer than three years. Monitoring of the faunistic composition provided further

Figure 16. Changes in the taxonomic composition (benthic invertebrates) at the three monitoring points.



The presence of certain species whose larval stage is aquatic (here an adult mayfly) is a sign of environmental quality.

One year following the transfer of the WTP, the dominant crustaceans had disappeared and been replaced by the diptera. The molluscs and the ephemeroptera were the first to return, followed by the trichoptera, the odonata and the turbellaria. The coleoptera would seem to have had severe difficulties in resettling in the area and the plecoptera remained absent. On the whole, sensitive taxa have the potential to return rapidly, but it takes time to return to large, stable communities. The evolution of the downstream communities starting in 2010, *i.e.* with a higher number of taxa sensitive to organic matter and nutrients, confirmed that the environment was on the road to a progressive recovery.

This study revealed the beneficial effects for invertebrate communities of an improvement in the treatment of urban wastewater. But for situations like the Vistre River, confronted with major disturbances along most of its length, restoration work must address a larger scale and integrate efforts to improve not only the chemical quality of the water, but also the physical habitat.

Hypotheses to explain fish mortality in the Loue River

The Loue River, an tributary to the Doubs River and a site of excellent fly fishing, has become in just a few years a symbol of the damage done to aquatic environments in the context of global change. Exceptionally high mortality rates (particularly for brown trout and grayling) occurred in 2010 and 2011 along several reaches. Environmental associations and the local population reacted strongly, which led to the creation, at the request of the Prefect of the Doubs department, of a national group of experts managed by Onema. The group of eleven, chaired by Jean-François Humbert (INRA), was assigned the task of explaining the death of the fish and any possible links with the development of toxic cyanobacteria observed at the same time in the river bed. The results of the study were made public in March 2012 in a detailed report (available on the Onema site at http://www.onema.fr/rendu-durapport-d-expertise-sur-la-loue) and during the symposium on aquatic biodiversity.

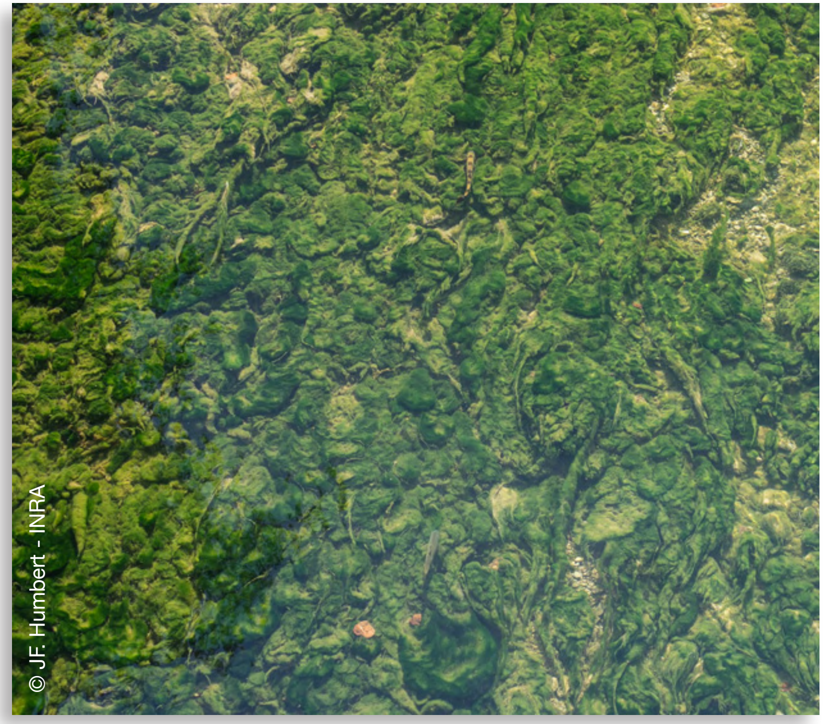
The experts first worked for a year on previous scientific publications and data provided by an array of sources, including the Rhône-Méditerranée-Corse water agency, in conjunction with a local group. They arrived at the conclusion (J.-F. Humbert, INRA) that there was no direct link between the fish mortality and the presence of the toxic cyanobacteria.

In the absence of a clearly identified, manifest cause (pollutants or pathogens), the group shifted to a new hypothesis, *i.e.* that the fish mortality and the proliferation of cyanobacteria were two extreme symptoms of a recurrent malfunction in the river. Consequently, they worked on characterising the river and its catchment, and on detecting the causes of the malfunctions, in a context of insufficient data for many parameters, notably the concentrations of micro-pollutants from farming activities and from wood-treatment processes, due to a lack of suitable monitoring.

The analysis revealed that numerous structures (small dams, weirs, etc.) along the river contribute to temperature rise and create ecological discontinuities. In addition, large quantities of biomass in the form of benthic algae and aquatic plants were observed in many areas, signalling the abundant availability of nutrients, particularly phosphorous and nitrogen. The growth of large quantities of biomass resulted in alterations to habitats and in temporary anoxia in some places, leading to a loss of biodiversity among the communities of primary producers and to disturbances in food webs. This explains the observed decreases in the abundance and richness of benthic-invertebrate and fish communities, and typological shifts with downstream species replacing those upstream.

To explain these physical-chemical and biological modifications, the work group then looked at changes in the anthropogenic pressures weighing on the Loue River basin. Over the last decades, there has

Can you find the two trout lost in this maze of benthic algae in the Loue River?


© JF. Humbert - INRA

been considerable population growth in the basin, which led to an increase in household pollution, notably phosphorous, PAH-type pollutants and, most probably, medication. The development of dairy farming and modifications in farming practices resulted in the increased release of nitrogen and certainly of pesticides. Finally, the expansion of the wood industry involved the extensive use of insecticides and fungicides. The impact of these chemical pollutants was certainly magnified by the fact that the karstic substratum of the river basin is characterised by a thin layer of soil and the presence of sinkholes that accelerate the transfer of surface pollutants to the aquifer networks and then to the river.

In the final analysis, the malfunction of the ecosystem would appear to be the result of a series of multi-factorial causes in which local human activities play a dominant role. In concluding its report, the group of experts listed a set of recommendations on operational aspects, monitoring and scientific policy. On the operational level, the group argued notably in favour of the rapid identification of the main, local sources of phosphorous and nitrates in the river basin in order to better monitor the flow of nutrients to the river. It also recommended more rigorous regulation of human, polluting activities given the special vulnerability of the river basin. Finally, it requested that the ecological continuity of the river be improved by removing certain weirs and dams. In terms of physical-chemical monitoring, the group suggested the creation of a scientific council in charge of coordinating all the monitoring programmes on the Loue River to correct the current situation characterised by heterogeneous data of poor quality.

Finally, concerning scientific policy, the group listed several priority topics for research to better understand the current operation of the Loue River and gain more knowledge on:
• the toxicological pressures weighing on the river and their impact on the organisms living there;
• modifications in the operation of the karstic system;
• the factors determining the proliferation of cyanobacteria and their toxicity.

4.2 – Discharge regimes and fish populations

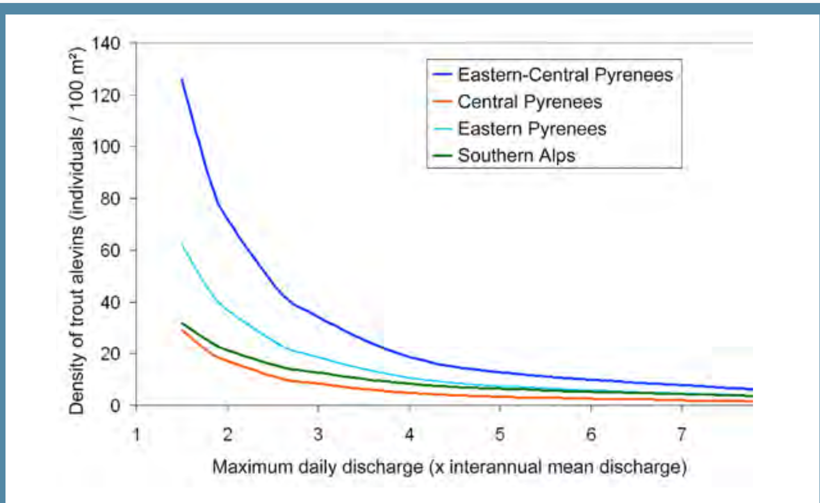
Freshwater, the enabling medium for aquatic biodiversity, is also a vital resource for human societies. In France in 2006, the total quantity of abstracted water amounted to 32.6 billion cubic metres (largely drawn from superficial water bodies), of which 5.75 billion did not return directly to the natural environment. Of the latter, 49% was used for irrigation, 24% for drinking water, 23% for energy production and 4% for industrial uses (Ecology ministry, 2007). It is widely acknowledged that climate change and particularly social-economic trends (population growth, changes in land use) will result in an overall increase in abstractions. If aquatic biodiversity is to be preserved, this pressure on the resource represents a major problem in that the hydrological regime of a river (the variations in discharge) dictates its morphology and consequently the natural habitats that develop in the river and the plant and animal communities living there.

Half (49%) of the water drawn from the natural environment is used for irrigation.

Increasing amounts of research have been put into the links between hydrology and biology over the past 15 years. Above and beyond the concept of a "minimum biological discharge", instituted in France by the Fisheries law in 1984, scientific work has revealed the need to maintain an annual discharge regime if natural balances are to be preserved (Naiman *et al.*, 2002). Key variables have been proposed to determine the discharge regime (Poff *et al.*, 1997), *i.e.* the instantaneous discharge values, the recurrence interval of certain events, the duration of certain discharge values, the foreseeability of events and discharge stability.

In light of the above work and as part of the hydromorphological section of the WFD, Onema launched studies on the links between hydrological regimes and biodiversity. A number of quantitative examples, drawn from different research programmes, were presented during the symposium (Ph. Baran, Onema, B. Bergerot, HEPIA) to illustrate the links. Floods, for example, have a significant effect on migratory fish, as was already highlighted in section 1.3. for salmon and sea trout in the Bresle River. Monitoring on the Allier River, between Vichy and Poutès, confirmed that high spring and fall discharges were a positive factor for the upstream migration of salmon. Concerning eel, monitoring on a river in the Vendée region (see section 4.5.) revealed that glass eels and elvers travel upstream in far greater numbers when discharge levels in the spring and summer are higher. There is also a close relationship between the success rate of brown-trout alevins and flood levels. Roughly speaking, the density of the juvenile fish drops sharply if floods occurring when the alevins leave the spawning grounds are greater than five times the interannual mean discharge of the river. However, this relationship varies depending on the region, as shown in Figure 17.

Figure 17. Influence of floods on the success rates of trout alevins in different regions.



Floods are a natural phenomenon and an indispensable part of normal river operation.

Similarly, low flows influence certain fish populations, notably in the downstream trout zone. A reduction in QMNA (monthly low flow for a given year) by a factor of 2.5 results in a decrease in the biomass of brown trout by a factor of 2 to 6, depending on the region. Stone loach and minnows, on the other hand, increase in number when low-flow levels decrease.

HEPIA and Onema have decided in favour of a large-scale analysis in an attempt to link hydrological characteristics and biodiversity by combining the data from the fish surveys (data from 10 893 fishing sites stored in the BDMAP database) and the HYDRO database, which contains the hydrology data from 4 827 monitoring points throughout continental France. Drastic selection criteria were used. Only fishing surveys carried out at sites for which at least four years of fish monitoring data were available were short-listed. The corresponding hydrological data had to come from a monitoring point in operation for at least 20 years. The sites of fishing surveys and the monitoring points could not be separated by an obstacle or by a tributary. As a result, 127 sets of fishing-survey sites/monitoring points were selected for this study throughout continental France. The results will determine the hydrological requirements in setting up operational restoration projects, in a collective effort covering entire river basins.

4.3 – Weirs, dams and habitat fragmentation analysed using genetics

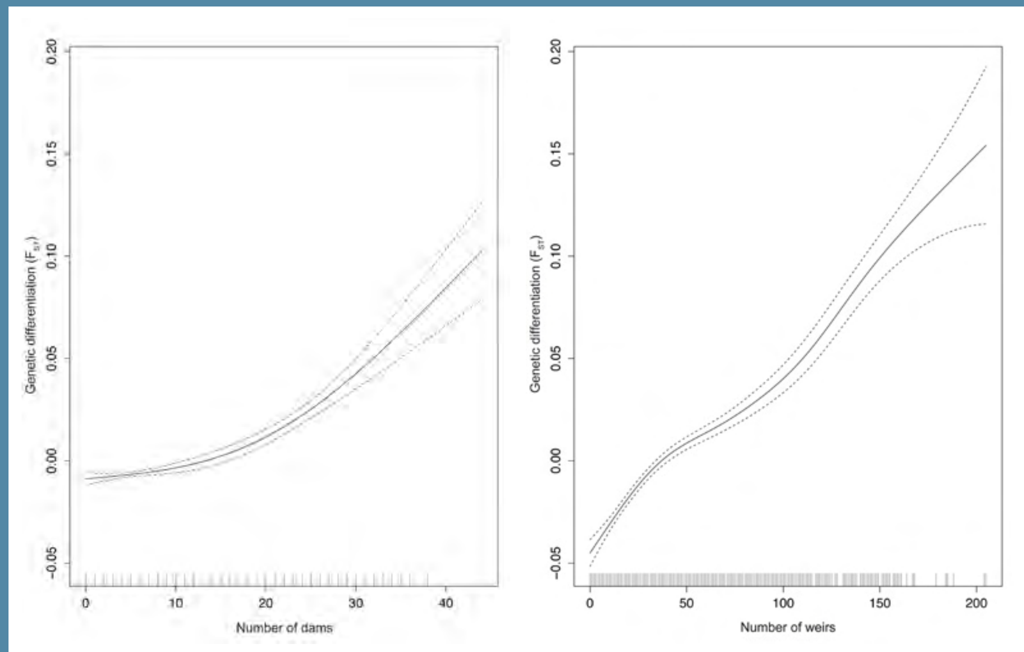
In any given river, it is very important to maintain a sufficient hydrological regime, but that may not be enough to preserve biodiversity. Weirs, structures and dams located along a river frequently alter its operation and thermal regime very profoundly.

In France, a total of 550 large dams, 2 500 to 3 000 hydroelectric plants and over 50 000 weirs have been inventoried. They break the ecological continuity of flow, fragment habitats and hinder the movement of aquatic species. That is, of course, the case for migratory fish (the eel is the topic of section 4.5.), but it is also the case for all freshwater fish because populations may be isolated by obstacles and thus weakened, similar to the Rhône streber (see section 4.4.). To quantify the impacts on fish populations, a useful *in situ* approach consists of measuring indirectly, using molecular tools, the movement of the fish of a given species. This movement may be limited by obstacles blocking the fish.

This approach was employed by a scientific team (Simon Blanchet, Géraldine Loot, Vincent Dubut, Ivan Paz-Vinas, Charlotte Veyssières, CNRS) on rivers in South-West France, using chub and gudgeon as biological models. The first step consisted of running an overall analysis on the entire Garonne River basin. Using specimens from over 90 sampling sites, two genetic metrics were calculated for each species and each pair of sites, first genetic differentiation, which characterises the long-term dispersal of populations (more than ten generations), secondly the number of dispersing individuals, which characterises a short-term dispersal (less than two generations). The results were analysed taking into account the number of dams (H>3 metres) and weirs (H<3 m) between each pair of sites. They confirmed that the number of dams and weirs has a significant impact on the genetic differentiation of the two species (Figure 18). There is a linear increase in genetic differentiation between two sites in step with the total number of dams and/or weirs between the two sites, *i.e.* the greater the number of obstacles between two sites, the more the movement of fish is limited.

A mill dam may contribute to a non-negligible degree to the isolation of fish populations.

Figure 18. Influence of the number of obstacles on the genetic-differentiation index of the chub. Dams on the left, weirs on the right.



Over the short term, the results for the species differ. No impact was observed on the number of dispersing individuals for chub, but the number of weirs had a significant effect on the number of dispersing individuals for gudgeon. In-depth study on the behaviour of the two species and their biodemographic strategies will be required to explain this result.

The second part of the study attempted to measure the effect of each obstacle in two small rivers in the same basin, namely the Célé and Viaur Rivers, in which 20 and 16 obstacles were analysed respectively. For this part of the study, the species selected were gudgeon and minnows. Samples were taken directly upstream and downstream of each obstacle. Four parameters were noted for each obstacle, *i.e.* height, slope, water depth and distance from the source of the river. The team measured population connectivity between each pair of sites upstream and downstream of an obstacle on the basis of four molecular indices, including the differentiation index mentioned above. Analysis of the indices revealed a surprising result for the Célé River, *i.e.* the farther the obstacles were located upstream, the worse the connectivity. The results were more predictable for the Viau River in that the decisive parameter was the height of the obstacle.

Generally speaking, the study confirmed the usefulness of molecular tools in quantifying the impact of obstacles on the dispersal of populations and consequently in identifying the most harmful obstacles in view of setting management priorities. It also highlighted the fact that each river has its own specific characteristics which makes it difficult to generalise the results of local studies. Further work is required to refine the connectivity indices and turn these techniques into tools to monitor the effectiveness of restoration work.

4.4 – Modest but encouraging results in efforts to conserve the Rhone streber

The case of the Rhône streber (Zingel asper) is a remarkable example of the impacts of habitat degradation on aquatic biodiversity. Also called the Rhône apron, this endemic fish is classified as critically endangered in the IUCN Red list. In 1900, it could be found in 2 000 kilometres of river throughout the Rhône basin, but today, it is observed in only a few sections of the Swiss part of the Doubs river and in the Loue, Ardèche, Drôme, Durance and Verdon Rivers, representing a total of approximately 300 km (Figure 19). The causes of the decline are well known. The fish is a poor swimmer, has a low fecundity rate and requires unaltered habitats with clean, clear water at a temperature under 30°C. It is particularly sensitive to structures that fragment its habitat and reduce low-flow rates. Further problems include pollution and extraction of gravel, which increases the turbidity of water.

A number of action plans have been implemented for the species since 1994, first by the Rhône-Alpes regional directorate for the environment, subsequently in the framework of the Life Nature projects 1 and 2 with support from Onema. An assessment of these efforts (P. Roche, Onema)

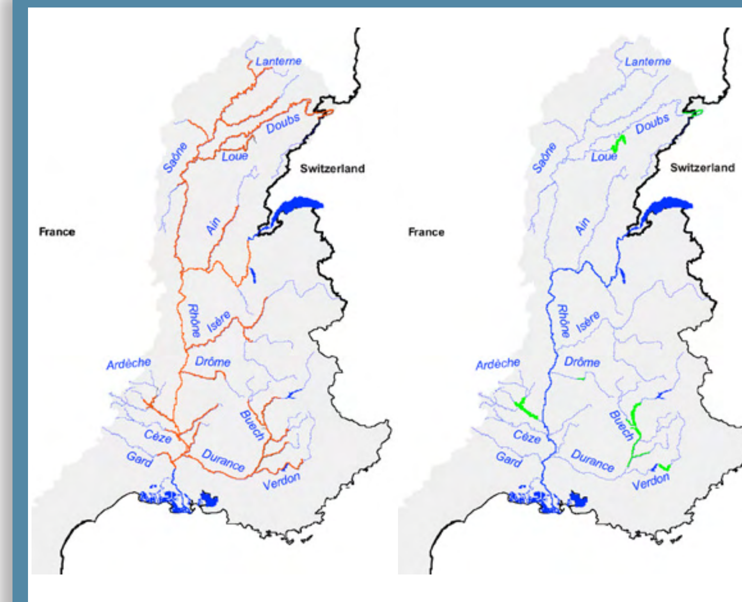


Figure 19. Distribution ranges of the streber in the beginning of the 1900s (left) and now (right).

The Rhône streber, a fish found almost exclusively in France, is critically endangered according to the IUCN.

was presented during the symposium. Restoration of ecological continuity is a major component. The Saillans dam on the Drôme River was removed in 1994, followed by the dam at Serre on the Buëch River and the dam at Sainte-Tulle on the Ardèche River. Seven fish passes have been installed on the Ardèche, Drôme and Loue Rivers. These efforts are now producing effective results. Over the past few years, the streber has recolonised several kilometres of the Ardèche River, upstream and downstream of Lanas. In the fish pass at Quingey on the Loue River, the streber is now the second species most frequently observed. Increases in population have also been observed in the Buëch River.

These encouraging results confirm the progress made in restoring hydromorphology and water quality, which made possible restocking and translocation projects. One example is the project for the Drôme River, proposed in 2001. The streber had virtually disappeared from the river in spite of newly favourable conditions. The river first received an influx of fish from the Durance river in 2006, than alevins from the Ardèche region, obtained through ex situ reproduction by the Museum in Besançon since 2008. Restocking using other alevins, obtained from reproducers in the Durance River, is planned for 2013.

The Rhône streber has not given up yet and managers still have a number of possible measures in hand to improve conditions, *e.g.* pursue efforts in favour of ecological continuity, limit micro-weirs created for bathing and canoeing, increase sediment loads, etc. Serious concerns still exist, however, because some isolated populations are threatened over time due to their insufficient genetic diversity and others due to increases in summer water temperatures because access to upstream reaches is blocked. Efforts to restock and assist populations must take these two constraints into account in order to put the available means to best use.

4.5 – 18 R&D projects to reduce the impact of installations on the European eel

Eels were once prevalent in almost all European aquatic environments, but have undergone rapid decline in just a few decades. It is now one of the four species of fish in continental France, similar to the Rhône streber, classified by the IUCN as being critically endangered. This alarming situation is the result of several anthropogenic factors. The migratory species has suffered from water and sediment pollution, overfishing and poaching. Its very complex life cycle has been particularly impacted by human alterations to habitats and obstacles to river flow. During upstream migration, glass eels and young yellow eels are confronted, starting right in the tidal zones, with an array of structures that limit their access to upstream habitats, including locks, tide gates, crest and sluice gates, etc. Farther upstream, large dams are often very difficult to overcome. And then at the end of its life, when what is now a silver eel starts out on its downstream migration to spawn in the Sargasso Sea, it must again overcome the same obstacles and many of the future reproducers go through hydroelectric turbines risking serious injury.

In 2007, a proactive protection policy was established throughout Europe (European regulation EC 1100/2007), which resulted in France in a management plan designed to ensure escapement to the sea of at least 40% of the silver-eel biomass that would have existed if no anthropogenic influences had impacted the stock.


© D. Poracchia

Eels were abundant in most rivers and marshes in France in 1900, but the return of juveniles has since dropped by over 95%.

This goal led the Ecology ministry to prepare an R&D programme on installations blocking rivers, comprising a coherent set of 18 research projects carried out in the framework of a partnership between Onema, Ademe and five hydroelectric companies.

Lasting three years, this unprecedented research programme acquired new knowledge on eel ecology, ranging from the kinetics of the upstream migration of glass eels to the environmental and hydrological parameters that trip downstream migration of silver eels (L. Beaulaton, Onema). A wide range of technical solutions were identified and tested in view of quantifying the impacts of structures and optimising their design, *e.g.* admission of saltwater through tide gates, sizing of brush passes to assist elvers in overcoming dams, resistive counters to measure the effectiveness of the solutions, etc. For downstream migration, silver eels were equipped with transponders to understand how they react on arriving at obstacles and determine the percentage of the fish passing through the turbines. Other tests assessed *in situ* the impact of different types of turbines on the fish. Still other studies worked on sizing the screens at water intakes to block entry of the fish in the turbines and to determine the effects on electricity production. Work was also put into designing fish-friendly turbines and validating their performance levels *in situ*. In addition to studies on individual installations, the R&D programme also developed models to analyse the impact of series of installations along entire river sections. The progress made produced the knowledge required for a technical and economic analysis to develop new management plans for turbines, including precisely timed shutdowns during peaks in downstream migration.

All of the above work and the results of the R&D programme were presented in detail in "Optimising the design and management of installations in the framework of the management plan to save the eel", published in 2012 in the Meeting Recap series. The information is a necessary step for managers and economic stakeholders in setting up the solutions that will help, on the various management levels, in achieving the objectives set by the eel management plan.

Spotlight

On the use of historical documents in understanding biodiversity

The value of viewing changes in biodiversity as part of long-term processes is widely acknowledged by the scientific community, yet most of the current work covers periods of a few decades, at best. Historic documents, when they exist, may constitute extremely valuable sources of information to widen the time spans of the analyses on the links between biodiversity and anthropogenic pressures. This approach was implemented by Irstea, with support from Onema, on fish populations in the Seine River basin (S. Beslagic, Irstea). A team collected documents written by naturalists and scientists toward the end of the 1800s and beginning of the 1900s, as well as archives from the Agriculture and Pubic Works ministries, produced by engineers at the Bridge and road agency or the Water and forest agency. Following processing, the resulting stock of documents contained 4 317 observations (presence or absence) concerning given sites and/or periods. A database called CHIPS (catalogue of historic information on fish in the Seine) was created to analyse the data. For each record, the database contained the name of the taxon, the water-body name and category (river, canal, lake), the geographic site and the date of the observation. Depending on its existence, additional information was stored, *e.g.* species abundance, introduction or restocking, disappearance, biometrics, health status, etc. Information on the type of observation (direct, second-hand, survey, etc.) served to determine the quality of the data. CHIPS now contains information on a total of 211 rivers (and some 20 canals) and 58 taxa have been identified, plus a few crayfish. Initial processing of the data made it possible to determine the distribution ranges of certain species such as salmon (Figure 20).

The team also found 18 reaches for which historical data (1840 to 1970) provided a “complete” list of species with information on their abundance. Combined with data from recent electrofishing campaigns, this information informs on the composition of populations at different times and consequently on the population dynamics in the reaches.

Analysis of the population dynamics reveals much larger changes in the structure of populations over the long term than those noted over the short term, *i.e.* the recent period. For example, the increase noted in rheophilic species (fish that like flowing waters) would appear to be a significant, long-term trend. This observation may be linked to modifications in hydromorphology, in particular the draining of many ponds over the period studied.

On the whole, the use of historical data for a long-term analysis of the links between biodiversity and anthropogenic and/or hydroclimatic pressures is highly worthwhile when studying a number of ecological issues. It contributes to better knowledge on flagship species and the colonisation techniques of non-native species, and it serves to more precisely define “reference states”, a notion used for the IUCN Red list, whose criteria include changes in the distribution of a species since the 1700s. It would appear possible to expand the time span of such studies, even to the point of including archaeological data. The team also suggests transposing the technique to other river basins if the necessary data are available.

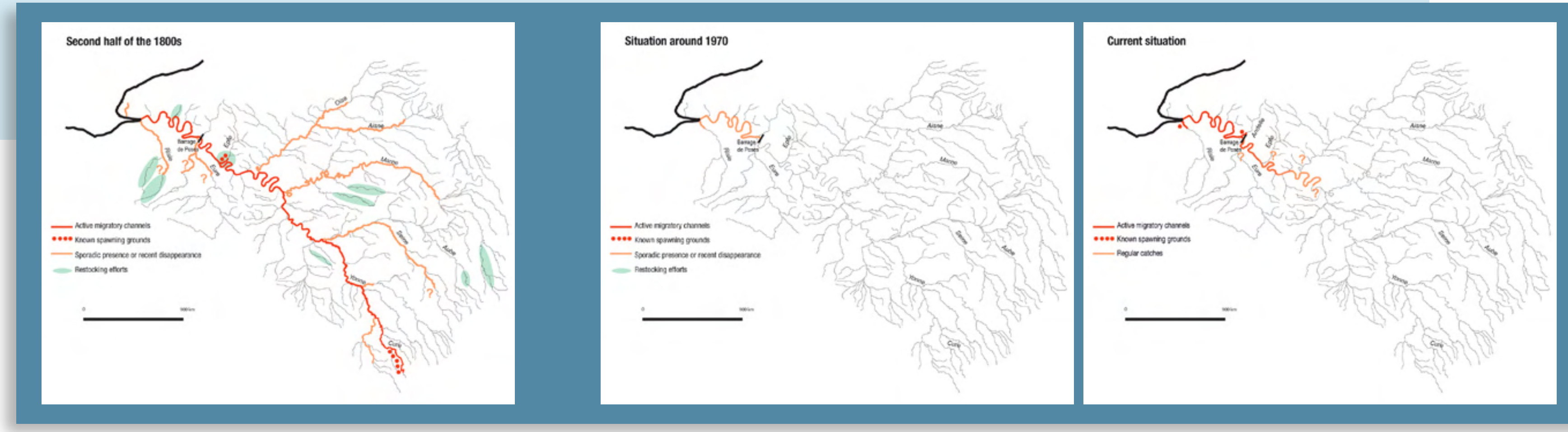


Figure 20. Changes in the distribution of salmon in the Seine River basin during the second half of the 1800s, in 1970 and today.

invasive species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Invasive species, also called alien or exotic species, are both a component and a consequence of global change. In just a few decades, they have become a major concern for the managers of aquatic environments. Plants such as water primrose and watermilfoil (Myriophyllum), arriving from Asia, Africa or the Americas, have colonised European rivers, in some cases to the point of totally disrupting ecological balances. The signal crayfish, among others, was imported to Europe commercially, but now exerts strong pressures as both a competitor and a pathogen vector on the native species, many of which are now threatened with extinction. The Louisiana crayfish provokes profound disturbances in the operation of invaded ecosystems. Exotic fish such as the topmouth gudgeon and the Albanian roach have appeared in European rivers, canals and lakes, and in some cases reproduce massively (see section 1.2.).

How can the ecological impact of a plant or animal on the colonised environment be assessed? To what extent does it constitute a pressure on aquatic biodiversity? What management techniques must be implemented to limit the pressure and at what cost? Each species raises a different set of problems and the answers to the above questions are often complex and controversial. This last section presents a number of observations, tools and viewpoints to assist in coming to grips with the problems.

5.1 – GT-IBMA for discussions and action nationwide

Given the complexity of the management problems created by biological invasions in aquatic environments, managers expressed the need for scientific, technical and regulatory support. In response and following a proposal by Cemagref (now Irstea), Onema created a dedicated work group in 2008, called GT-IBMA.

E. Mazaubert and A. Dutartre (Irstea) presented GT-IBMA (work group on biological invasions in aquatic environments), which combines a unique set of skills, including managers (regional nature parks, Water agencies, ONCFS, etc.) and stakeholders (FNPF, Agriculture ministry, etc.) who provide feedback from the field on projects, difficulties and questions, institutional players (Ecology ministry, local governments, etc.) who keep the work group in touch with national and European issues, and finally people from the botanical conservatories and the various research institutes (Irstea, INRA, CNRS, MNHN, etc.), who input their scientific knowledge and experience.

Some exotic species can be particularly invasive, for example water cabbage (Pistia stratiotes).

Thanks to such a wide set of viewpoints, GT-IBMA is in a position to define a set of national guidelines to manage biological invasions in aquatic environments, to assist in developing operational tools for managers and to orient scientific policy on the topic. The group also supports and coordinates the work carried out on various levels, *e.g.* on the EU level where a European strategy on invasive species is now being developed, in France where the public authorities have published a National strategy for invasive alien species (continued regulatory development, increased efforts against the species and to raise public awareness), and finally on the local level where many groups and organisations involved in species management are active.

The goal undertaken by GT-IBMA, in collaboration with the technical coordinators at the Ecology ministry in charge of implementing the national strategy, is to draft and validate a list of invasive plant and animal species in continental France, and to develop an assessment method for the risks involved. To that end, it has launched a number of projects, *e.g.* the symposium on "Management of invasive species in aquatic environments" held in October 2010 (http://www.onema.fr/IMG/pdf/rencontres/Onema-Les-Rencontres-9.pdf), a survey on invasive species and their management in aquatic environments, a study on water primrose in the Brière regional nature park, etc. The group will also publish in 2013 a "good-practices guide" on managing invasive species in aquatic environments and other guides will be forthcoming.

All of this work is presented in detail on the internet site at www.gt-ibma.eu (Figure 21). In response to increasing requests from managers, the work group intends to develop economic methods to assess the management costs incurred by the invasions.

Figure 21. Home page of the www.gt-ibma.eu site.

The riparian vegetation along the Adour River has undergone significant changes due to anthropogenic pressures and notably the introduction of species.

5.2 – Serious ecosystem alterations in the Adour River

The effects of a biological invasion always take place progressively. To determine the status of an ecosystem at a given point in time and make the correct management decisions, it is necessary to understand how the processes play out over time. With that goal in mind, a study examined the evolution of floristic compositions in the riparian zones along the Adour River (E. Tabacchi, CNRS and member of GT-IBMA). An identical group of observers carried out complete floristic surveys (presence/absence of species) in 1989, 1999 and 2009, on 32 sites along the river from the source to the mouth.

They noted profound changes in the river dynamics due to anthropogenic causes with major consequences for plant biodiversity. For example, in the Bernède meander (Gers department) the number of observed species fell from 673 to 383 and the number of distinct habitats from 29 to 16. Surprisingly, no significant modification was noted in the total species richness (approximately 2 000 species). The changes consisted essentially of a "redistribution" with a clear trend towards more uniform compositions between the upstream and downstream sections, particularly between 1989 and 1999. This trend towards greater uniformity differed depending on the types of plant.

The competitive species, present primarily in the upstream reaches, regressed only slightly, however the stress-tolerant species retreated significantly in the upstream and downstream thirds of the river basin (Figure 22).

Among other major changes, hydrophytes (submerged or amphibious plants) underwent notable regression in the downstream section of the river, while ruderal species (plants growing spontaneously in disturbed areas) increased along the entire river. Finally, introduced species also developed strongly. They now represent on average over 25% of the species observed on a given site, compared to 17% in 1989 (Figure 23).

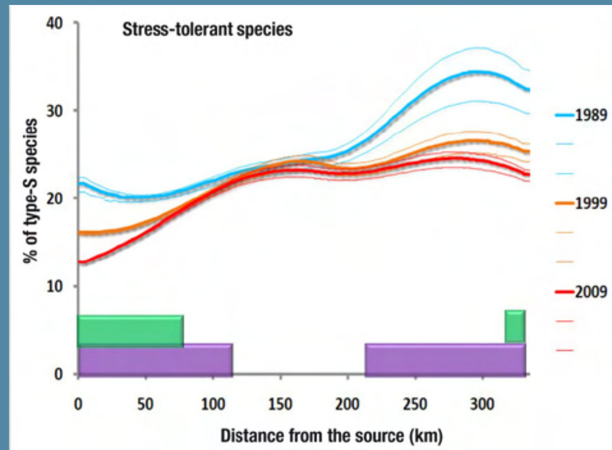


Figure 22.
Spatial and temporal evolution of stress-tolerant species (as a % of the total number of species) in the riparian corridor along the Adour River. The horizontal bars indicate the zones of significant change (purple between 1989 and 1999, green between 1999 and 2009).

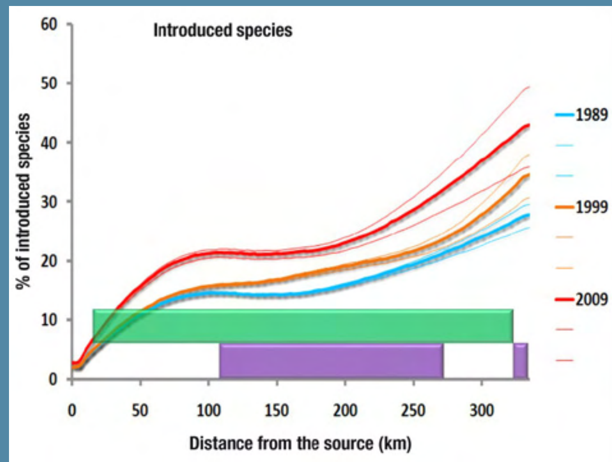


Figure 23.
Spatial evolution of introduced species (as a % of the total number of species) in the riparian corridor along the Adour River.

The overall results are fairly diverse. The high level of diversity (species richness) that still exists would suggest that the ecosystem has potentially strong resilience to meet anthropogenic pressures (urbanisation, agriculture, fragmentation of the landscape) and climate change. However, that must not divert from the fact that the composition of plant communities has undergone profound changes. The disappearance of specialist species (often flagship species) may be linked in part to the invasions, but modifications in habitats remain the primary cause. It should also be noted that alien species are not responsible for all the invasions. Native plants may become invasive if an ecosystem suffers imbalances.

In terms of the method employed, the highly robust results (evolution curves) incited the authors to suggest their use for the development of ecosystem bioassessment tools. This long-term study will be pursued and the authors are now planning the development of a quantified functional approach to assess the effects of changes in composition on the functions and services rendered by ecosystems.

5.3 – Economic approaches to problems

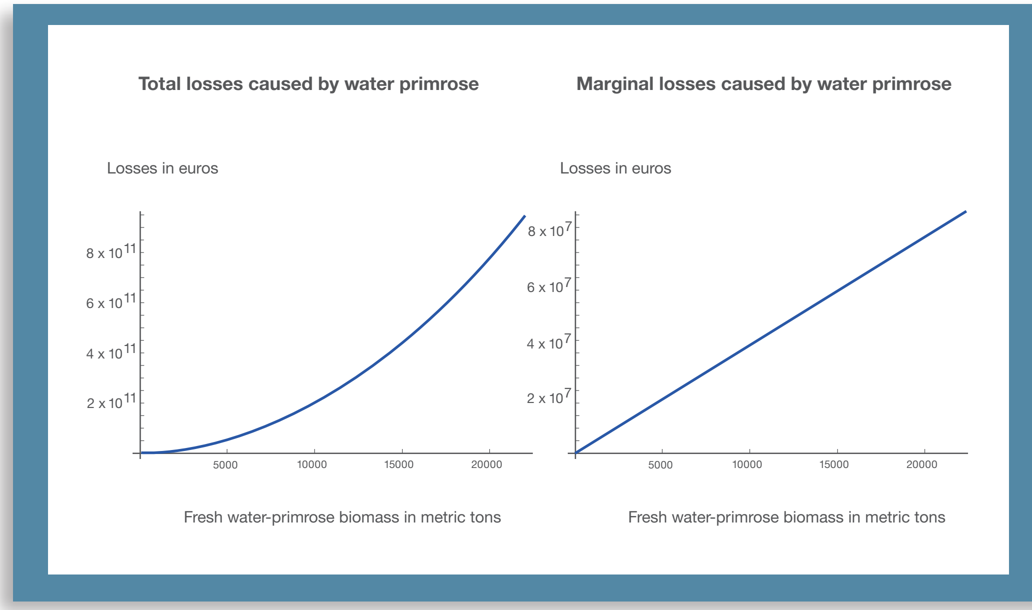
To assist in the management of biological invasions, economic approaches have for several years been an increasingly important research topic. A study on water primrose (A. Thomas, INRA in a partnership with GT-IBMA) was among the first projects launched in France. The aquatic plant has a certain aesthetic value when its densities remain low, but it tends to invade natural environments if no control measures are taken, leading to ecological damage and economic losses.

The objective of the study was to model the relationships between the growth rate of the plant, the resulting effects and the cost of control measures, in view of creating a method to calculate the "optimum stock" of water primrose in a given area. Using a set of theoretical functions, the management costs were put into an equation linking the present quantity of biomass and the quantities that must be extracted to manage the various impacts (commercial and non-commercial) of the invasion.

This method was applied to the wetlands of the Marais Poitevin region in Western France. The various impacts were analysed and calculated in terms of the economic loss. Among the commercial impacts, water primrose results in a loss of tourism revenue due to more difficult navigation on canals, in agricultural losses, in higher risks of flooding due to silting of rivers and in significant nitrate pollution if the plants cover the entire river. The non-commercial impacts include not only the loss of biodiversity, but also the aesthetic degradation and the difficulties caused for fishing and hunting. All of the above parameters were taken into account by the model to produce an estimate of the total economic losses, in euros, as a function of the biomass (Figure 24).

After including the management costs, the calculations produced an estimate of the "optimal" quantities of water primrose for the Marais Poitevin area corresponding to 87% of the current quantities. Water managers expressed considerable interest for the model during the symposium. The model can, of course, still be improved.

Figure 24. Costs incurred by the invasion, as a function of the total water-primrose biomass.



One of the major assumptions is that the length of infested river is directly proportional to the quantity of the plant. A further and very common limitation to this type of approach lies in the difficulty of taking into account all the impacts caused by the invasion and determining their economic value. In particular, the question of "monetising" the services rendered by biodiversity continues to be a subject of controversial debate.

Removal of water primrose in the Brière regional nature park.

Conclusion

The symposium organised by Onema on 14-15 November 2012 consisted of approximately 30 presentations demonstrating the great variety of scientific approaches employed in France to understand the mechanisms governing aquatic biodiversity, to assess its current status and to develop the tools and methods that will enable water managers to work more effectively to restore biodiversity in the future.

The data on the current status of biodiversity revealed the harm done by global change and human activities to the fauna and flora of aquatic environments in France where over 20% of freshwater-fish species are considered threatened. But the future will be what we make it. For example, the analysis of the time trends carried out by Onema would suggest a relative improvement in the status of fish populations due notably to the efforts over the past 30 years to enhance water quality. The feedback from projects, *e.g.* for the Rhône streber, demonstrate that projects to restore biodiversity, if correctly implemented, can produce good results. The regulations concerning aquatic biodiversity (Habitats directive, Natura 2000 network, Water framework directive) provide water managers with the necessary legal framework to take action. Similarly, the work to restore water bodies driven by the WFD and the corresponding technical progress (bioassessment tools, new survey methods, etc.) will contribute, above and beyond the monitoring and reporting objectives, to greater knowledge on biodiversity and how to preserve it.

Aquatic life, from microbial communities to macrophytes, from Dytiscidae water beetles to pike, is the result of a complex set of physical-chemical balances and trophic interaction between the living communities and their environment. Each human intervention, whether an increase or easing of pressures, restoration work, etc., produces effects throughout the environment. The preservation of aquatic biodiversity must go beyond the management of species and populations to address the dynamics of ecosystems, their complexity and their resilience. This necessity is now a guiding force in the development of integrated approaches to aquatic biodiversity, examples being the IUCN efforts to assess ecosystems, the development of functional bioassessment tools and the use of mesocosms in research projects. The data presented on the links between river discharge regimes and biodiversity, or on the impacts of obstacles to flow show that the good hydromorphological status of environments is a decisive factor in their overall operation and contributes to the integrated restoration of living communities.

Current scientific approaches to biodiversity are also becoming increasingly multi-disciplinary. For example, the symposium reported on the recent contributions of biocomputing and molecular tools in assessing the status of populations. Historical documents are also a precious source of information in efforts to expand the time horizon of studies. The development of economic approaches, integrating the emergent notion of ecosystem services, has become a major research topic in view of providing assistance in making management decisions. Methods were presented during the symposium on how to assess the vulnerability of wetlands and determine the costs of a biological invasion. This multi-disciplinary opening of the biodiversity field must now be expanded to include other human and social sciences that are, to date, less active. Their contributions will shed light on social perceptions concerning aquatic biodiversity, on the expectations that biodiversity raises and, consequently, on the values and services attached to ecosystems.

Finally, the dissemination of the data and knowledge acquired, via documents and tools supplied to the different groups, including scientists, water managers, economic players and citizens, remains a priority because the restoration of biodiversity will require, more than ever, progress in our collective awareness.

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