Change in the climate and in the biodiversity-conservation paradigm The case of diadromous fish

Restoration projects are set up for the most threatened species to recreate a former situation considered more satisfactory. But the climate change that has already taken place in certain regions has made it impossible to return to the former situation.

The concept of biodiversity is still recent and biodiversity conservation has been gradually set up as an extension of and the next step for the preservation of habitats and of fauna and flora, through a number of international conventions (see table ❶). In spite of specific aspects and differences in approach, these directives and conventions have many similarities in terms of the species, habitats and ecosystems addressed and all act in synergy to avoid further damage and even improve the situation.

Restoration projects were set up for the most threatened species to recreate a former situation considered more satisfactory. Given the time required to significantly improve the situation for a threatened species (or habitat), most restoration plans are still underway. National parks, nature reserves, biotope-protection decisions, special areas of conservation and, more recently, marine protected areas (*cf.* Pasquaud et Lobry, p. 122-125 in this issue) are all excellent means for biodiversity protection. They cover rare biotopes and/or essential habitats for threatened species of fauna and flora. All of these texts and their operational/regulatory documents implicitly assume a planet that is in equilibrium and without its own dynamics.

Diadromous fish, threatened species

There are 28 species of diadromous fish in Europe including 11 in continental France. In the course of their life cycle, these species undertake long migrations between marine and river habitats. Some, called catadromous, spawn in the ocean, yet most of their growth takes place in rivers. Examples are the European eel (see photo ❶), thinlip mullet and European flounder. Others, called anadromous, spawn in rivers and most of their growth takes place in oceans. Examples are the sea and river lampreys, European sturgeon, Allis shad, Twaite shad, European smelt, brown trout and Atlantic salmon. Among the species present in continental France, eight are now managed in compliance with the various directives and conventions (see table ❷).

Strong links between climate and species distribution

For a given species and on the basis of observations of its historic distribution area (theoretically, its distribution in the absence of anthropogenic pressures, i.e. "pristine" conditions), it is possible to formulate an explanatory model. The "grain" of these large-scale approaches is generally fairly "coarse", e.g. in our work on migratory fish, the selected basic unit was the river basin. The explanatory factors selected for these statistical models (different types may be used, e.g. generalised additive model, neural network, proportional odds model, boosted regression tree, etc.) may be of different types, but they are most often abiotic (biogeographic, climatic, edaphic, hydrological, etc.). For example, the factors selected to explain, using a generalised additive model, the observed distribution (presence/absence) of Atlantic salmon around 1900 (Lassalle *et al.*, 2008) are the average annual air temperature at the mouth of the river basin (°C; TempAnn), the longitude at the mouth of the river basin (°; Long) and the surface area of the river basin (km²; Surf):

$$\text{Equation} = \text{Salmo\_salar} \sim s(\text{Long}, 2) + s(\text{Surf}, 2) + \text{TempAnn}$$

For given spatial and temporal scales, we attempted to refine the relationship by constructing a model taking into account species abundance in one of four classes, i.e. absent, rare, common, abundant (Lassalle et Rochard, 2009). To that end, we selected a proportional odds model. In this case, the selected factors were the surface area of the river basin (km²; Surf), source altitude (m; Elv) and average air temperature during the summer (°C; TempSum):

❶ The European eel, a threatened species

❶ **Main directives and conventions to preserve biodiversity, applicable in continental France, with place, date and abbreviation.**

Conventions et directives	Place	Date	Abbreviation
Convention on wetlands of international importance	Ramsar	1971	Ramsar
Convention on international trade in endangered species of wild fauna and flora	Washington	1975	CITES
Convention on the conservation of European wildlife and natural habitats	Bern	1979	Bern
Convention on the conservation of migratory species of wild animals	Bonn	1979	CMS
European directive on the conservation of wild birds	Luxembourg	1979	BIRDS
Convention on biological diversity	Rio	1992	CBD
European directive for the preservation of natural habitats and wild plants and animals	Brussels	1992	HFF
Convention for the protection of the marine environment of the north-east Atlantic	Paris-Oslo	1992	OSPAR

❷ **Protection level (managed [listed], strictly protected [listed +]) for migratory fish in continental France by the international conventions, French and world red lists drawn up by the International union for the conservation of nature (IUCN France, IUCN world) and French management committees for migratory fish (Cogepomi, 1994).**

	HFF	CITES (May 2009)	Bern	Bonn	OSPAR (2004)	IUCN France (December 2009)	IUCN world (February 2009)	Cogepomi (1994)
Sea lamprey	Listed		Listed		Listed	Near threatened	Least concern	Listed
River lamprey	Listed		Listed			Vulnerable	Least concern	Listed
European sturgeon	Listed	Annex 1	Listed +	Listed +	Listed	Critically endangered	Critically endangered	
European eel		Annex 2				Critically endangered	Critically endangered	Listed
Allis shad	Listed		Listed		Listed	Vulnerable	Least concern	Listed
Twaite shad	Listed		Listed			Vulnerable	Least concern	Listed
European smelt							Least concern	
Brown trout						Least concern	Least concern	Listed
Atlantic salmon	Listed		Listed	Listed	Listed	Vulnerable	Near threatened	Listed
European flounder						Insufficient data	Least concern	
Thinlip mullet						Least concern	Least concern	

Equation = pol (Surf, 2) + Elv + pol (TempSum, 2)

In both cases, a temperature factor was used in the models.

We know that temperature influences most biological phenomena and species life-history traits. That is particularly true for ectothermic species such as fish (Ficke *et al.*, 2007) and amphibians. It would thus seem clear that when the distribution model for a species includes a temperature factor, any important change in climate will cause, over time, a modification in its potential distribution area. That is illustrated, for example, by the changes in species distribution since the last glacial period.

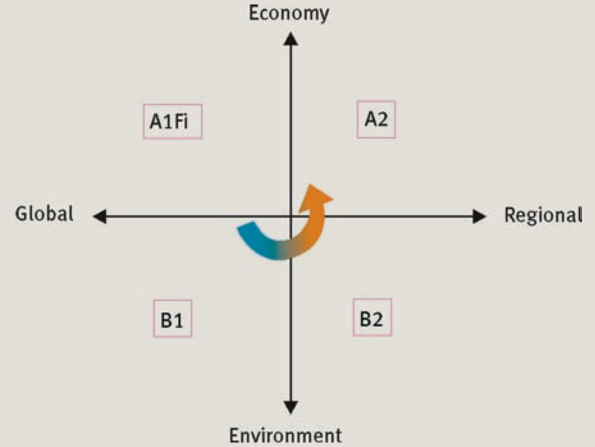
A clear situation

Plant and animal species can adapt to climate change. That can occur in the same place through modifications in species life-history traits (if climate change is limited and the species are not at the edge of their distribution area) or by moving. In Europe, lower temperatures can generally be found at higher altitudes or points north of the initial area.

Over the past decades, many plant and animal species have shifted their distribution areas northward, on average 6.1 km/decade. Among migratory fish, the European smelt (which likes cool waters) has disappeared from the Garonne river basin and shifted the southern limit of its distribution area northward. On the other hand, Allis shad and thinlip mullet (which like warmer waters) now regularly colonise river basins in Normandy, i.e. they have shifted the northern limit of their distribution areas northward.

The same phenomena may be observed for migratory birds which adjust to environmental conditions even faster. These species now winter further north due to the increase in temperatures. Conversely, colonisation by southern species is now occurring, particularly for wintering and nesting purposes.

❶ The four sets of socio-economic scenarios for greenhouse gas emissions.



Greenhouse-gas emissions increase counter clockwise from B1 to A1Fi (arrow).

Is global warming an additional pressure?

In France, the air temperature increased, on average, 0.7 to 1.1°C over the 1900s and the last decade of the century was the warmest recorded over the past 150 years. Concerning precipitations, the Mediterranean coast became drier over the past 15 years while western and northern Europe became wetter.

Each of the possible world socio-economic trajectories produces a different climate-change trajectory. Four main scenarios for world socio-economic changes were selected by IPCC (Intergovernmental panel on climate change) – see figure ❶.

Depending on the scenario, temperatures could increase 1.5 to 3°C by 2050 and 1.5 to 6°C by 2100. At the same time, an acceleration in the water cycle and increases in regional differences are expected, e.g. equatorial and polar zones will become more humid, Mediterranean and tropical zones drier.

The climate changes corresponding to these scenarios for the coming century are very strong and rapid compared to the last glacial period (Würm, 18 000 BP). It is thus probable that fauna, flora and habitats will be strongly affected by the modifications. Climate change is certainly an additional pressure that will considerably increase the threats weighing on certain species (notably those that prefer cooler temperatures).

The need for a paradigm change

Species conservation has to date been implicitly based on the myth of a stable environment (the list of species considered native to a country and justifying eradication of other species illustrates this mindset whereby distribution areas do not change). Restoration of a threatened species aims to recreate a former situation, deemed more satisfactory. To that end, it would "suffice" to correct the damage to the habitat of the species, limit the pressures exerted, even help it by boosting the population or weakening predators. For certain flag species, e.g. the Atlantic salmon, major political commitments were made and high budgets devoted to their restoration over the second half of the last century. The measures taken hindered its disappearance even though, to date, the overall results are mediocre due to the failure to correctly acknowledge all the constraints weighing on the species.

Unfortunately, the climate has started to change again, after many millennia of virtual stability. It influences directly (temperature, rainfall, wind) or indirectly (river flow rates, ocean levels) species distribution and, in Europe, the current trend is a northward shift in the distribution areas of species. Strictly for climatic reasons independently of regional anthropogenic pressures, a favourable habitat for a species in 1900 could easily become unfavourable by 2100. Conversely, a previously unfavourable habitat could become favourable.

If we accept this new context, it would appear most unlikely that in the near future, any given place will return to the climatic conditions it knew one century ago. Consequently, species conservation will be a reasonable undertaking only in the river basins that offer now and will offer one century from now favourable conditions for that species. In light of the above considerations, that may not correspond in many cases to the historical distribution of species.

Simulation of potential distribution areas

Using the models presented above, it is possible to simulate the potential distribution areas of a species according to different scenarios.

For example, figure ❷ below presents the potentially favourable river basins for Atlantic salmon under one of the more pessimistic socio-economic scenarios (A2, see figure ❶). The climate data are drawn from the TYN SC 2.03 database and were processed in the HadCM3 coupled atmosphere-ocean model for the period 2070-2099. This example makes clear a drastic reduction in the number of river basins presenting favourable climate conditions for Atlantic salmon (see figure ❷). According to this scenario, the species would retain a central zone offering favourable climatic conditions, but would lose its southernmost basins and some of the basins south of the Baltic Sea. No river basins would become favourable for the species.

Using the same A2 scenario, most species of European migratory fish would, similar to the Atlantic salmon, see their potential distribution area contract (see figure ❸). Only the thinlip mullet *Liza ramada* and the Twaite shad *Alosa fallax* would see their potential distribution area increase. The situation would remain virtually unchanged for species in the Caspian sea. Potential distribution areas diverge progressively from the historic situation in step with the sequence of four scenarios in figure ❶.

Similarly, this type of forecast indicates the most heavily impacted regions (gain or loss of favourable conditions for a large number of species) and those less impacted. For migratory fish, the studies forecast a loss of specific diversity in southern Europe (Iberian peninsula, southern France) and a gain in central Europe (Germany, Poland). The Ponto-Caspian region would be less affected.

For other taxonomic groups, changes in specific diversity may differ depending on the historic distribution areas and any possibilities to leave zones farther to the south. That is the case, for example, of marine species arriving from the Red sea via the Suez canal to the Mediterranean coast.

The implications

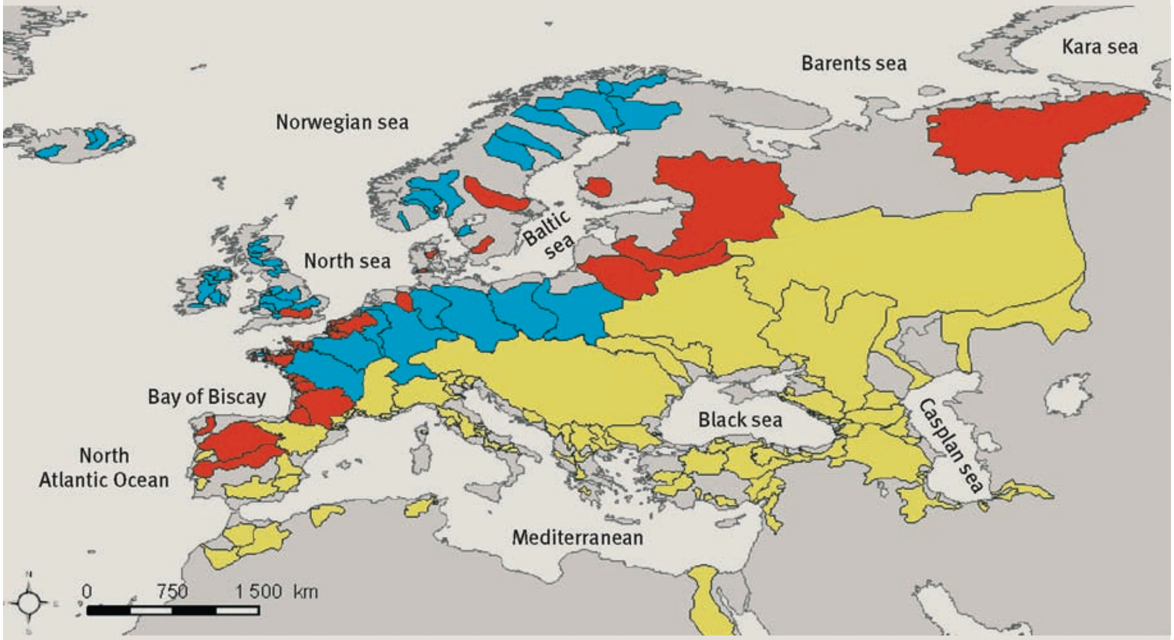
For species that prefer cooler temperatures, the situation will become more difficult, whereas it will become easier for species that enjoy warmer temperatures.

In light of the forecasts for distribution areas, the general observation may be made that geographic aspects of biodiversity conservation and restoration must be put back on the drawing board. The most useful zones, now or in the future, for biodiversity conservation and restoration of threatened species are not necessarily those in which protection and restoration measures have been set up. Recent work has shown that, for a number of species groups of African animals, existing nature reserves may in the future no longer be particularly favourable for the species for which the reserves were established.

It would also appear that certain restoration projects are no longer realistic where they are currently set up and should be moved to other sites.

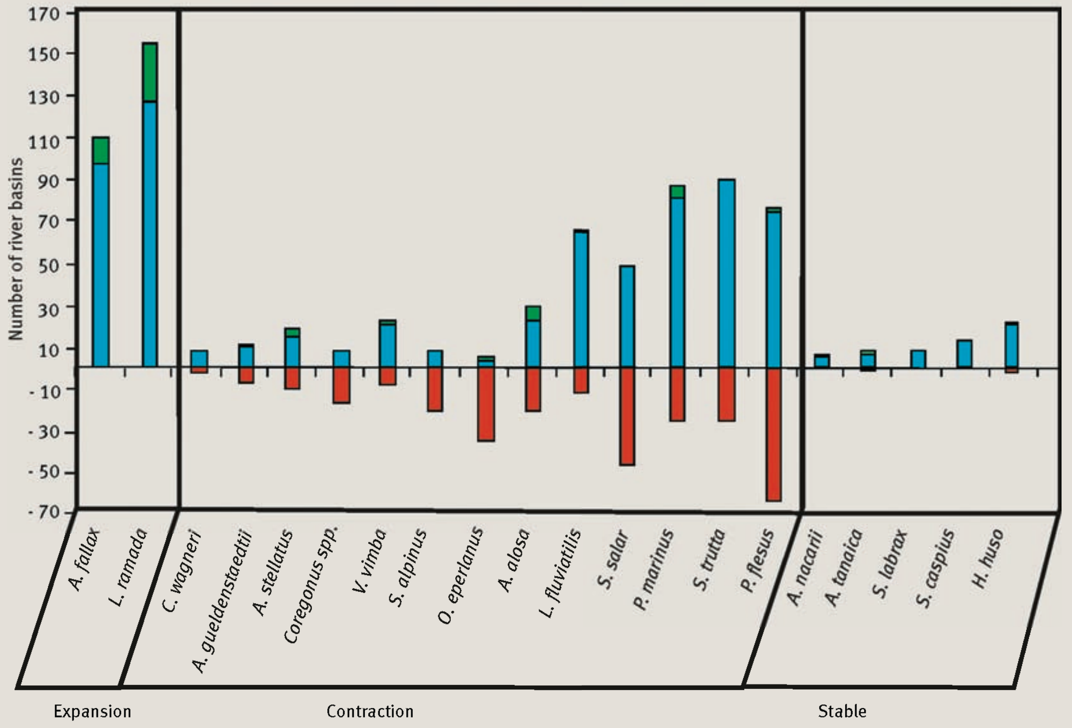
Fragmentation of European landscapes is likely to hinder emigration of many species to new regions with a more favourable climate. Adaptation of a species to cli-

❷ Potentially favourable river basins for the Atlantic salmon. (scenario A2, 2100).



Yellow basins are those without salmon in 1900 and for which the presence-absence model does not forecast a change by 2100 given the selected scenario. Red basins had salmon in 1900, but will become unfavourable by 2100 according to the scenario. Blue basins had salmon in 1900 and will remain favourable in 2100 according to the scenario.

❸ **Change in the number of potentially favourable river basins for different species of European migratory fish.**



Blue indicates the number of river basins that will remain favourable in 2100, red the number that will no longer be favourable and green the number that will become favourable. GAM simulation model, GCM HadCM3, scenario A2, period 2070-2099 (Lassalle *et al.*, 2008).

mate change will depend, to a large degree, on its ability to disperse and find suitable habitats (Branch, 2007). That is why the National ecological network (*cf.* in this issue : Bergès *et al.*, p. 34-39 ; Amsallem *et al.*, p. 40-45 ; François *et al.*, p. 110-115 ; Piel et Van peene, p. 116-121) agreed upon during the Grenelle environmental meetings is, in theory, a particularly suitable means to preserve species by enabling them to travel and settle elsewhere.

Reactions to study results of this type

Among environmental managers and project initiators, reactions vary depending on whether they work on a larger geographical scale (European, national, regional) or on the river-basin scale. The first are very interested by the research undertaken on a scale that suits them (both spatially and temporally) and provides them with forecasts on future trends and the species that may be affected. The second group is also interested, but generally expresses doubts about an approach that explicitly does not address their scale (neither spatially nor temporally). Depending on whether the results are favourable for them or not, they accept them without hesitation or deny them any value and contest the statistical approach used or the climate models selected as the input variables.

There is a clear North-South gradient to the reactions. In our example with migratory fish, river basins located in northern Europe may encounter more favourable conditions for several species and are generally happy with the results. Southern river basins, on the other hand, may be confronted with less favourable conditions for most species, a result that is particularly unpleasant for managers who feel they have made great efforts to improve the situation with respect to regional anthropogenic pressures.

In certain cases, it would appear that certain environmental managers are even willing to accept considerably more artificial living conditions for a species that they consider particularly important, e.g. the emblem of a region.

Conclusion

Many doubts remain concerning the causes and rate of climate change, but the initial consequences for species distribution and life-history traits may already be observed. Given this situation, historical conditions are no longer valid indications for action plans targeting biodiversity conservation. The forecasts for potential distribution areas according to the various scenarios have become unavoidable factors in assessing and setting priorities among different restoration options, in a forward-looking approach. Not only species must adapt to climate change, but also biodiversity-conservation measures and practices. Whatever the final scenario, restoration of geographic continuity in both land and aquatic environments is a measure that should facilitate the establishment of new distribution areas by allowing species to physically move as needed. ■

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