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Preserving the richness of aquatic environments

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Freshwater is a vital resource. But subjected to the simultaneous effects of climate change, pollution and overexploitation, water resources have become fragile. Models are used to study the consequences of water preservation measures.

Rivers, lakes and wetlands, also referred to as freshwater hydrosystems, represent only 0.6 percent of the world's water but host 6 percent of the total number of animal and plant species. As such, they are an important reservoir of biodiversity and play a key role in a variety of biological cycles. But they are as susceptible to climate change as the terrestrial ecosystems with which they are connected. They are vulnerable because climate change is happening on a global scale and because they are also submitted to the impact of human activities.

Increasing air temperatures will contribute to warmer water temperatures and disrupt water transfers through for example, a change in the date of snow melt. These transfers control not only the quantity of water in transit, but also the organic and mineral components being transferred.

This will change the soil composition and vegetation in the river watersheds (terrestrial systems with which the hydrosystem is connected). As a result of modifications in the volume, nature and intensity of rainfall, the quantity and availability of water that reaches the hydrosystems will change. Aquatic organisms will face a variety of modified physicochemical conditions in their environment, for example declining concentrations of dissolved oxygen in water.

It is essential that we study and understand the impacts of climate change on hydrosystems to suggest either mitigation or adaptation strategies. However, the variety and complexity of these impacts hinder our ability not only to identify them, but also to predict their occurrence and intensity.

Presented here is a review of current research focusing on the adaptation of hydrosystems to climate change, bearing in mind that aquatic systems did not benefit so far from as much attention as terrestrial ecosystems.

Impacts on water quantity

The reduction of fresh water availability is one immediate consequence of climate change. In many regions, water resources are already insufficient or used too intensively to ensure replenishment of the stocks. In the future, agriculture will require even more water to satisfy an increasing human population (19 percent increase by the year 2050). As a result, more intense competition for access to water resources for agricultural, industrial, household, recreational and environmental activities is anticipated.

Temperature increases stimulate both evaporation and evapotranspiration (water loss by plants), which, combined with a decline in precipitation, threatens hydrosystems with drought in temperate zones, for example in the marshes of western France. Water flow in rivers should decline by 20 to 25 percent by the end of the century and this is also expected to come with longer low water periods. At the same time, extreme rainfall events should multiply flood occurrence or periods of high water.

By reducing the quantity of water circulating in hydrosystems, climate change would also prompt a decrease in the hydrological connection between the different parts of a river (upstream, downstream, estuaries and tributaries), therefore enhancing habitat fragmentation.

Ecological adaptations

Increased average temperatures will cause a warming of water, the magnitude of which will vary depending on the altitude and water supply to the watershed. Between 1977 and 2006, annual average water temperatures in the Rhone river increased by 1.5°C, and summer temperatures taken from the middle of the Loire river rose by 1.5° to 2°C. In Lake Geneva, as for a dozen of other Swiss lakes, deep waters have warmed by 1°C over 40 years; the winter temperature of the total water mass rose from 4.5°C in 1963 to 5.15°C in 2006.

Hydrosystems host numerous cold-blooded animal species, notably fish, whose physiology relates directly to temperatures. As such, global warming of water may induce cascading effects on the composition of fish communities. The maintenance of fish populations faced with environmental changes depends on the species capacity to adapt. Adaptation may come from phenotypic plasticity (as, for example a change in shape or size, without modifying their genetic characteristics), or can arise from selection mechanisms triggering changes in the genetic composition of the population (provided the genetic variability within the population is sufficient).

For instance, triggers for reproduction, egg development and fry survival in Arctic char *(Salvelinus alpinus)*, require temperatures ranging between 3 and 7°C. Warmer waters in winter would jeopardize reproduction and maintenance of Arctic char populations living in the Great Alpine Lakes in France, their southernmost habitat in Europe. In contrast, in these same lakes, the two-week delay in whitefish reproduction in December is compensated for by a shortening of the duration of its embryonic development and finally whitefish populations appear to benefit from climate effects.

The decrease in individual sizes as observed for salmon population appears to be related to changes in both environments they occupy, i.e., increasing temperatures and acidification

Monitoring salmon populations

A significant increase in the growth of juvenile Atlantic salmon population over the last 40 years has been observed in a small river in Brittany. It was initially attributed to the rise in water temperature due to climate change, but finally proved to be the result of an increase in productivity in the river correlated to inputs of nitrates. Additional studies over the past 20 years indicate that the primary factor affecting growth for salmonids in Brittany is definitely not water warming.

How consistently explore the effects of climate change on fish populations? Virtual experimentation through model simulation provides important new insight. INRA is currently developing a simulation tool to study Atlantic salmon populations currently at risk in French rivers. This simulator integrates a diverse range of modalities for environmental factors related to climate change and the processes linking the different life cycle phases. It will give the opportunity to explore how populations adapt both with and without genetic change.

First simulations showed that, in an initial phase, increasing river water temperature would promote the survival of individual fish, but that it can also lead to earlier sexual maturation, which tends to have a negative influence on survival rates. Virtual experimentation also offers the opportunity to prioritize the various components of climate change relative to their effects. As such, for the next 30 years, changes in the hydraulic regime (notably flow) in rivers should be a higher concern for the persistence of salmon populations than rising temperatures.


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of the marine habitat combined with higher temperatures and altered water flow in rivers. In large water systems, species adapt by modifying their spatial distribution. Along the Rhone river, near Bugey nuclear power plant, thermophilic species, such as the barbel and the dace, are gradually replacing cold water species, such as chub, encountered further upstream. Although there are several evidences of the impacts of climate change on fish communities, predicting long-term consequences affecting populations in freshwater environments beyond these selected examples remains a wide open field for research.


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The estuaries and gulfs, such as this one shown in Riga, on the Baltic Sea, are at risk of disappearing. They will not be able to continue acting as nurseries for marine species.

Changes in hydrosystems

Because temperature affects water density (reaching a maximum at 4°C, then lowering when temperatures increase), climate change also affects the dynamics of water masses in lakes. Stratification periods, when warmer water layers float on colder layers, alternate with periods when the lake water mixes. But the relative duration and intensity of each of these periods are affected by climate change. Warmer springs have prompted stratification to occur one month earlier than it did 30 years ago, effectively extending the duration of stratification.

The seasonal succession of planktonic species has in turn been modified. Thirty years ago, algae or cyanobacteria species, that are adapted to grow in deep waters where they face sedimentation, proliferated mainly in autumn. Nowadays, they appear at the end of the summer and have longer life spans. As these are filamentous species, sometimes even toxic, they tend to accumulate at the bottom of lakes and disturb the supply of drinking water. Furthermore, changes in wind patterns and decreasing flows of tributaries also contribute to limiting the efficiency of water mass mixing in winter and oxygen replenishment in deep waters. As such, bottom deoxygenation in the Great Alpine Lakes has increased over the past 20 years, threatening life in deep waters.

Changes in rainfall on watershed basins are also altering the quantity and nature of transported organic matter and nutrients. In northern Europe and in Britain, water in streams has become increasingly brown over the past 20 years. Brownification is due to increasingly warmer and dryer summers, and to severe thunderstorms. Both of these factors contribute to an increased displacement of soluble material from soils to streams. The sensitivity of soils to erosion is expected to increase in the forthcoming decades, causing an increase of river sediment loads. Combined with lower flows, higher particle flux is likely to reduce the transparency and quality of water, and will prompt a decrease in habitat diversity for fish and invertebrates. Moreover, gas solubility, for carbon dioxide and oxygen, will decrease with rising temperatures, promoting both the risk of water deoxygenation and the release of extra carbon dioxide into the atmosphere.

Lastly, the rise in ocean levels will increase the risk of coastal areas becoming more or less covered by saltwater. If estuaries are invaded by saltwater, their essential role as nurseries for marine species will be altered, and a number of plant and animal species they normally host will disappear. Freshwater resources of coastal aquifers are also endangered due to salinization.

Climate change is already perturbing hydrosystems, but observed changes do not always result in a loss of biodiversity or in the quality of the environment. Over the course of the last 15 to 25 years, the diversity of fish communities in large river systems has increased because of the presence of fish species of more southern origin. Some of these species are invasive, that is, they multiply at the expense of local populations. Although this changes the biodiversity, the new species could reveal themselves to be essential in the future as they might be better adapted to changing environments.

Added to accelerating climate changes observed for more than 50 years, are local human pressures. Evaluating the respective roles of climate change and human pressures on


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Severe thunderstorms foster soil erosion and increase sediment transport. As a result, water quality may be adversely affected.

changes in ecosystems will be required in order to decide on the most effective actions for preserving hydrosystems.

Strategies for adaptation

Freshwater systems and the species they host have natural abilities to cope with climate change, particularly through population migration and adaptive capacities. However, excessive human pressures (agricultural, industrial and urban) on the environment reduce this adaptive potential. Consequently, these environments may deteriorate too rapidly for species to adapt, which would increase the vulnerability of hydrosystems.

Adaptation strategies are aimed at restoring or enhancing hydrosystem resilience facing climate change. The goal is to manage water availability and biodiversity in a way that would be economically viable but also based on resource sharing and optimized use. This can be done by saving water via technical actions (reducing leakage, recycling), financial measures (imposing progressive pricing to reduce water consumption), implementing changes in practices (agricultural, industrial or domestic) and making necessary adjustments for a more equitable and responsible distribution of resources. In addition, territory development should be revisited to avoid concentrated exploitation in the same areas and to promote natural water management.

To ensure continuity in the water cycle and at the same time meet the needs of agriculture, water balance in soils has to be maintained. This is the balance between inputs (precipitation, runoff, capillary rise from groundwater tables) and outputs (runoff, evaporation at the ground level and through evapotranspiration, drainage). This can be achieved by slowing the speed of flow and by encouraging infiltration through the limitation of impermeable zones, and through maintaining depressions in the soil or natural floodplains, wetlands and stream courses.

Regarding biodiversity, natural adaptation mechanisms should be fostered. As a first step, it is essential to maintain populations of sufficient size and genetic diversity. Limiting exploitation of the most vulnerable species, controlling anthropogenic stressors (pollution, habitat destruction, introduction of invasive species) and maintaining or restoring migration routes, which support population connection and individuals exchanges (for example, installing fishways or removing obstacles), are several ways of promoting diversity. Natural adaptation mechanisms can be facilitated through direct intervention, for example, by assisting migration for the most vulnerable species. It should be noted that the most effective adaptation strategy to date still lies in preserving existing high quality habitats and in restoring those that have been degraded.

A vital resource

The adaptation of freshwater systems to climate change is a crucial issue, and its success will rely on the commitment of users as well as managers. Because there are so many ways by which climate change can disrupt hydrosystems, it will be important to combine a variety of methods with temporal and spatial considerations (seasonal restrictions for water use, daily management of rainfall, sustainable use of fertilizers and plant protection products), at both local (fields, farms, cities) and global levels (watershed).

Considering that contradictory interests often exist, we will need to continue developing models that simulate both the behavior of hydrosystems and the populations they host, but also the effects of management measures intended to support their adaptation. These models will allow us to compare the impacts of recommended measures, whether they are designed for the protection or restoration of certain habitats or connectivity, and to enhance interactions between all actors for whom, quite simply, water is vital.

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