Freshwater fish and climate change
Current situation and adaptation strategies

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Foreword

The reality of climate change is no longer an issue. According to the annual climate statement by the World Meteorological Organisation, 2013 tied with 2007 as the sixth hottest year ever recorded worldwide, thus confirming the observed long-term warming trend. Temperatures were not unusual in continental France, however, a number of exceptional climatic events occurred such as the heavy snow and rain fall that led to flooding in the south-western section of France and the storms Christian and Dirk. As for 2014, it also confirmed the reality of climate change in that the month of May was the hottest ever since the start of records in 1880 (according to the U.S. National oceanic and atmospheric administration (NOAA)). In addition, the Intergovernmental panel on climate change (IPCC) recently increased to 0.6°C its estimate of the average surface temperature rise for the period 1951 to 2010.

The experts agree that the causes are anthropogenic, notably due to emissions of greenhouse gasses. It would seem obvious that this rapid and significant change in the climate will have an impact on all ecosystems and the dependent organisms, as well as on the ecosystem services that human beings count on. The organisation by France of the upcoming conference of the parties to the U.N. Framework convention on climate change (COP21/CMP11) that will be held in Paris from 30 November to 11 December 2015 is ample proof of the importance placed on the topic by France. The objective is that all countries, both developed and developing, accept a universal and binding agreement on the climate.

Lakes, rivers and marshes cover only 0.01% of the surface of the planet. In spite of this very small surface area, they are home to a vast number of species representing 9% of all animal species identified to date. They are also highly vulnerable to climate change if only because it has a direct impact on the water cycle. In addition, a majority of aquatic species are cold-blooded, which makes them even more sensitive to even the slightest modifications in the temperature of their environment. Finally, the climatic disturbances are simply another of many pressures, including excessive captures, water pollution, invasive species, etc. Climate change, whether in the form of increased temperatures or modifications in hydrological regimes, is thus fully capable of significantly altering the functioning of ecosystems.

That is why Onema supports research efforts to improve our knowledge on the effects of climate change, notably concerning hydrology and hydrogeology on the one hand, and fish populations on the other. Examples are the studies on the long-term changes in low-flow levels and groundwater levels, carried out by Irstea and

BRGM, respectively. Concerning fish, Onema has funded and contributed to various research projects such as those at Irstea on diadromous fish throughout Europe, those at the Université Paul-Sabatier (Toulouse III) on recent changes in the ranges of freshwater fish, those at the Université de Lorraine on the impact of warming on fish reproduction and the Explore 2070 project launched by the Ecology ministry. A great deal of the new information exited the ivory towers of academia and was discussed with water managers. This information also provided significant technical assistance in formulating the National plan for adaptation to climate change (PNACC) in 2011.

The overall objective of this book is to inform on current knowledge concerning the observed and projected modifications in the climate and hydrology, and the impact of these modifications on fish communities. Fish are particularly useful in determining the degree of change now under way in aquatic environments as well as the capacity of organisms to adapt (acclimatisation or migration). They live in virtually all surface waters, integrate the various anthropogenic pressures and constitute excellent indicators in the work to assess the ecological quality of aquatic environments. Finally, they play an essential role for human populations as a food source and in an array of socio-economic activities including commercial fishing, recreational fishing, aquaculture, etc. As a result, contrary to a majority of aquatic taxa, a mass of data (ecological knowledge, population monitoring, etc.) are available that are essential to understanding the processes involved.

Fish are the indispensable "indicator" species needed to both understand the modifications caused by climate change and implement the most suitable preservation policies for aquatic environments.

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Abstract

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This book is divided into four chapters. The first presents the current knowledge on observed and projected modifications in temperature, precipitation and river hydrology in a context of climate change. The different types of models producing the projections are discussed. The second describes the impacts of climate change already observed on the physiology, phenology and ranges of freshwater fish over the past few decades. The discussion takes into account both experimental and empirical studies. Three geographical areas are examined in detail, namely the Rhône and Seine basins and Lake Geneva. The third chapter discusses the existing models attempting to assess the vulnerability of freshwater fish in the future. Statistical distribution models are precisely described to put readers in a position to identify the data required to use the models, the correct scale for data interpretation and the uncertainties inherent in the models. Finally, the last chapter provides information on the adaptation strategies that can be implemented to reduce the vulnerabilities of fish in the future. The discussion will demonstrate that the recommended measures are largely compatible with existing laws and regulations.

Chapter 1 - Understanding the impact of climate change on water resources

The global climate has always fluctuated over time under the direct and indirect influence of various phenomena (orbital forcing, change in global albedo, disturbances in atmospheric currents, feedback loops). However, human activities releasing greenhouse gasses (GHG) and aerosols have clearly caused changes in the climate since the end of the 1800s, resulting in increases in air temperatures and the average sea level, as well as a reduction in snow-covered surfaces and ice caps. In continental France, analysis of long data series has produced estimates of average increases of approximately 1°C in air temperature and 1.6°C in water temperature over the last century. Loss of snow cover at medium altitudes is a further factor confirming that climate change is effectively under way. Other parameters, such as precipitation, evapotranspiration and surfacewater/groundwater hydrology, are also affected but the trends are not as clear given the difficulties in distinguishing between the effects of climate change and those of direct human activities.

To assess changes in the climate and in the various components of the water cycle (precipitation, evapo-transpiration, surface water, groundwater), climate models coupled with hydrological models have been formulated and calibrated for the various GHG emissions scenarios. For continental France over the coming decades, all climate projections (whatever the greenhouse-gas (GHG) emissions scenario) foresee warming between 1.5 and 3°C. Longer term, the projections diverge widely depending on the scenario and are much less reliable. They indicate warming from 2°C to more than 4.5°C by 2100. Concerning water resources, the projections for precipitation, evapotranspiration and discharges are more uncertain and differ depending on the model. However, evapotranspiration is expected to increase in the south-western section of France. Monthly mean discharges in rivers should decrease and low-flow levels should worsen over large parts of the country, particularly in the southern half. Finally, groundwater recharging may drop along with piezometric levels. Human activities will most likely reinforce the effects of climate change on water resources, notably due to increases in abstractions for drinking water and agriculture.

Consequently, even though there are numerous uncertainties concerning these projections, the potential impact of climate change on water resources in continental France should be considerable with a clear trend toward a reduction in those resources. Aquatic environments and fish in particular will be heavily impacted in the above scenarios.

Chapter 2 - Changes in fish communities in a context of climate change

The physiology, biological rhythms and distribution of fish depend on environmental factors such as temperature, hydromorphological conditions and water quality (dissolved oxygen, pollutant concentrations, etc.). Climatic disruptions impact these factors and thus constitute a major source of change for fish species.

Though it is very difficult in the freshwater context to distinguish between the effects of climate change and those of local anthropogenic pressures, a number of studies have revealed the impact of temperature increases on fish communities. Changes in certain physiological characteristics in response to an increase in water temperature have in turn resulted in changes in reproduction, growth and seasonal rhythms. In addition, some species have moved up river, extending their range when movement is not blocked by other factors such as weirs and dams. These movements have led to changes in the composition of communities with as a consequence modifications in species richness and in the number of dominant species.

Even though the signs are still not very clear in some rivers and interpretation is difficult due to anthropogenic pressures, the consequences of climate change are observable over France as a whole. They contribute to the impact of human activities in rivers (dams, reservoirs, sealing of banks, abstractions for various uses, release of polluted water, etc.) and can in certain cases reinforce the ecological modifications.

Unfortunately, the lack of long data series and the change in the sampling strategy for the surveillance-monitoring network limit the possibilities in terms of studying current changes in communities in the context of climate forcing. What is more, there is still a significant gap between ecological theory and on-site observations that requires in-depth research in this field.

Chapter 3 - Anticipating the impact of climate change on fish communities

Over the past few years, numerous tools have been developed to assess the impact of climate change on living organisms. Among those tools, statistical distribution models play an important role because they are based on simple assumptions and can project the potential habitat changes of a given species in response to different climate-change scenarios. In that certain ecological processes are not taken into account in these models, other tools, namely mechanistic models, have been developed in parallel. They are more powerful and robust, however they require much more knowledge on species biology. That is why their application to a large number of species has remained limited.

Even though the many underlying assumptions limit the possibilities of transposing the results locally, the projections produced by the distribution models reveal trends that can be used to assess the vulnerability of each species and any changes in the richness and composition of communities.

Generally speaking, all the models foresee a shift in the ranges of cold-water species upstream. The ranges of species living exclusively at the heads of river basins would be reduced to high-altitude refuge zones and the risks of their local extinction would be increased in certain lower-lying basins. Conversely, the conditions for species located in intermediate zones or downstream, such as cyprinids and centrarchids, would improve. On the community scale, an increase in species richness and greater uniformity of communities is expected in all rivers. In other words, the communities will be richer, but more similar to each other, resulting in a loss of diversity.

The vulnerability of species to climate change depends on the ecological requirements of each species and some of these requirements are currently not taken into account in the models for freshwater fish in continental France (dispersal capabilities, anthropogenic pressures, adaptive and evolutionary processes, etc.). A quantitative approach in conjunction with a critical analysis of the results based on expert knowledge would now appear to be a solution to refine the potential distribution maps for each species in the context of climate forcing.

In the future, the formulation of hybrid models combining both statistical and mechanistic models should make it possible to refine the projections produced by the distribution models, on the condition that the necessary data are available. The development of these models should proceed in parallel with the many research projects already under way to understand the pressure-impact relations (thermal pollution, minimum discharge, invasive species, etc.) that are factors in defining adaptive measures. Use of data series spanning long time periods, for both biological and environmental data, e.g. discharges, water temperature, etc., is also essential. In addition, it would appear that knowledge on species' ecology, even that of the most common species, is far too fragmentary and insufficient for mechanistic models. Filling in the gaps is a further priority. Finally, too few studies address time periods spanning the next decades, which are nonetheless an intermediate target of great importance for management. A great amount of work must be put into all the above topics.

Chapter 4 - Taking action to reduce the vulnerability of fish communities

Adaptation to climate change is a complex phenomenon that is already well under way in continental France. The National plan for adaptation to climate change (PNACC) laid the foundation in 2011 and produced a number of incentive and regulatory measures such as the Regional plan for climate, air and energy (SRCAE) and the Territorial climate-energy plan (PCET). In the water field, however, no new binding measures have been undertaken. That being said, the information presented in this chapter makes clear that the WFD measures already implemented constitute a highly effective tool in reducing the vulnerability of fish populations in a context of climate change. The increases in minimum discharges, the development of indicators such as the target low-flow discharge and efforts to reduce water consumption as stipulated by the PNACC are all important steps forward in the quantitative management of water resources. The restoration of ecological continuity, implemented country wide for all holobiotic (living their entire life in the same environment) and diadromous (alternating between freshwater environments and the sea) species will enable them to reach more favourable areas in the future in as much as the available habitat conditions (hydrology, physical-chemical parameters, etc.) are still favourable. Further imperative conditions are an improvement in water quality and the restoration of rivers, which will impact positively on the survival of fish in a changing environment. In spite of the uncertainties surrounding climatic and hydrological projections, climate change should be seen as a further argument to implement measures to attenuate pressures and thus enhance the resilience and adaptive capacity of environments and organisms.

Research programmes will provide knowledge on essential aspects such as the thermal and/or hydromorphological "preferences" of fish, their movements in rivers and their capacity to adapt or to acclimate. The relative impact of anthropogenic pressures compared to climate forcing and the links between water quality, water temperature and fish populations are further issues that require the attention of researchers. Finally, the uncertainties inherent in distribution models must be reduced in order to produce robust projections on smaller scales (e.g. the river-basin scale) in order to enable their operational use.

The continued operation and development of the observatories and measurement networks will be key factors in the future in both monitoring change and in assessing the effectiveness of the measures implemented. In the final analysis, it is important, on the one hand, to pursue and immediately amplify all types of work to restore and preserve correct functioning of aquatic environments. Their good health will make them more resilient to modifications resulting from climate change and thus reduce the vulnerability of species. On the other hand, it is important to continue the accumulation of data and research results in order to better understand, over the mid term, the phenomena involved and to improve the responses to those phenomena. The two approaches are essential because they complement each other.