Management and Impacts of Climate Change Programme
GICC
CRP 2000

3/00 – Potential consequences of climate change on aquatic and riparian biocenoses (1st phase)

Summary of Final Report

Coordinator: Didier Pont - CNRS

Action 1: Spatialization of thermal data at the national level
Rogers C. (UMR 5600 / UMR 5023)

This first activity deals with the setting up and validation of the thermal data needed for the other actions of the programme. It comprises three parts: (1) the spatial interpolation of monthly mean temperatures over France, (2) the verification of the correlation between water temperatures and air temperatures on a monthly basis, and (3) the integration of thermal anomalies produced by the climate change simulations. The creation of a base of monthly mean temperature estimates spanning 1980-99, i.e. 240 sets of measurements, is particularly useful in that it gives access to an evenly-composed base at the national level, common to the different regional ongoing projects, which made it possible to develop parameters optimized for ecological modelling. Interpolation was carried out on the basis of observations recorded by 534 Météorologie Nationale weather stations, through the kriging of temperature data reduced to their sea level equivalent according to the mean coefficient of the altitudinal thermal gradient in France. The estimates were then converted into real temperature estimates according to the altitudes of a kilometrical digital elevation model (EROS Data Centre, USGS). The independent control over a random selection of 120 stations shows a mean error of ± 0.59 °C and ± 1.84 °C at a 95 % confidence interval, while the analysis per control station shows that some of them display high errors, systematically either positive or negative (atypical cases). The whole set of monthly estimates was developed into a georeferenced database and distributed to the participants of the AQUABIO programme.

In hydrobiology, air temperatures are often used as substitutes for water temperatures. However, given the significance of thermal variables in the context of the project, it appears necessary to check the validity of this approach, in particular at a monthly time step and in relation with GIS estimates. A quick review of reference publications and several analyses carried out on various data series show that, in terms of annual variability: (1) the correlation between air and water temperatures is optimal for durations of 10 days and over on continuous time series ($R2 < 0.9$), (2) on discontinuous series per catchment (RNB[1] data from the national monitoring network), the general relationship is quite good ($R2<0.8$) and almost always better on individual stations or regional sub-populations ($R2<0.85$), and (3) the correlations obtained with the GIS simulations are as good as, or even slighter better than, those obtained with the RNB air temperatures.

[1] RNB : Réseaux Nationaux de Bassin (National Network of Catchments).

Five climate simulations were taken into consideration for assessing climate change impacts on aquatic and riparian biocenoses. Four low resolution simulations were provided by the Laboratoire de Météorologie Dynamique (LMD) of ISPL, Paris (LMD6 A (Sechiba) and B (Bucket) models, and A and B CNRM models). A fifth simulation, at a high resolution (ARPEGE+ISBA simulation with HadCM3, at variable resolution), was obtained directly from CNRM, Toulouse, to fine-tune the spatial representation. Thermal anomalies of the low resolution simulations were directly applied to the simulation mesh (200 by 300 km mesh size), but high resolution anomalies involved a regularized interpolation (spline function) to ensure a relative spatial continuity. Monthly anomalies were calculated by subtracting reference values from the simulations values, and then applied to the present-time temperatures of the GIS.

Action 2: Analysis of biological responses to climate variability through the study of time series.

2.1- The importance of hydroclimatic variability for the benthic macro-invertebrate communities of the lower Rhône

Bady P. and Dolédec S. (UMR CNRS 5023, Lyon1)

The analysis of the temporal response of benthic macro-invertebrates to hydrological and thermal variability is based on several series of sampling campaigns carried out in the lower Rhône by CEMAGREF of Aix-en-Provence and ARALEPBP (Lyon 1 University) between 1985 and 1999. Models that couple thermal and hydrological variables help to explain in part the trends in taxa richness and in the relative abundance of a small number of families over time. In the multi-species, multi-site and multi-date context of this study, multi-table analyses, still under-used in ecology studies, such as the Multiple CO-inertia Analysis (MCOA), prove optimal for the exploration of faunistic tables. This method is based on the generalization of co-inertia to more than two tables. It makes it possible to coordinate several analyses and to compare the reproducibility of the spatio-temporal organization of macro-invertebrate assemblages. It provides a clear representation of the intra-site variations in annual distributions of communities in relation to a reference structure. Our results underline the occurrence of a strong temporal structure, common to all sites, that prevails in spite of the plasticity of the spatio-temporal responses of the faunistic descriptors. These findings open a new field of investigations on the relevance of descriptors and of the methods used to describe community structure complexity.

2.2- Inter-annual variability of Cyprinid fish reproduction in the Rhône downstream from Lyon: The role of temperature

Carrel G. (U.R. Hydrobiologie, Cemagref Aix-en-Provence), Olivier J.M.(UMR CNRS 5023, Lyon1), Poirel A. (EDF, DTG Grenoble) and Breil P. (U.R. Hydrologie - Hydraulique, Cemagref Lyon).

At our latitudes, the reproductive success of running water fish species is largely governed by the concurrence of favourable physical conditions: a complex interaction between periodic and highly predictable environmental variables such as the length of the day and the temperature, and abiotic much less predictable factors that depend on the hydrology. The year to year variability of the reproductive success of Cyprinid species has been studied from fish farm data collected over 20 years (between 1982 and 2001) near nuclear power station sites along the Rhône valley. It is analysed in relation to thermal data collected as part of the self-monitoring procedure of these industrial installations. The analysis of the spring and

summer thermal regime of the Rhône downstream from Lyon used 21 descriptors of four daily temperature time series recorded by EDF over 25 years (from 1977 to 2001). Notable modifications of the regime have taken place since the end of the 1980s, with a rise in temperature, earlier yearly thermal thresholds, a shortening of the cold period and a lengthening of the warm period. Although temperature appears determinant for the reproductive success of the studied species, other abiotic factors such as those related to hydrological variability cannot be dismissed.

2.4- Effect of hydroclimatic variability on the Seine fish communities
Tales E. (U.R. Qualité des eaux, Cemagref Antony).

A similar approach to fish communities used the hydrobiological time series (1991-2001) of the Nogent-sur-Seine nuclear power plant. The variations of the hydroclimatic regime (discharge and temperature) were studied through a principal component analysis with 10 environmental variables. The fish community variations over time, available for three stations, were analysed through a multiple co-inertia analysis (MCOA). The reference temporal structure of the 25-species fish community is defined by six species. Bleak and Bream characterize the first years, Common Roach, Gudgeon and European Bitterling the intermediate years, and Pike, the year 2001. The other fish species do not follow a characteristic pattern throughout these 11 years.

2.3- Climatic factors and density-dependence
Grenouillet G. and Pont D. (UMR CNRS 5023, Lyon1).

On the population scale, fluctuations in juvenile Common Roach (*Rutilus rutilus*) abundance were studied over a period of 11 years (1987-1997) in four localities along the lower Rhône. Reproduction appears as a synchronous event along the whole of the river course, uncorrelated to the distance separating populations but directly linked to hydroclimatic factors. Mean water temperatures in June explain 55 % of the recruitment variability at the end of the growing season. In contrast, the analysis of the apparent survival of juveniles during their first winter (adverse conditions) highlights a significant relationship between this survival rate and their density at the end of their first year – i.e. a type of density-dependent regulation mechanism. This may explain the absence of inter-site synchronism in one-year-old juveniles. These results show that biotic interactions can significantly offset the consequences of climate variability on the stock of reproductive individuals in this species.

Action 3: Modelling biological responses at the national level

3.1- Fish species
Pont D. and Rogers C. (Univ. Lyon1-CNRS UMR 5023)

The aim is to assess the potential consequences of climate change on the fish species of French water courses, focusing on the aspects related to the increase in temperature. More specifically, it involves estimating the changes in favourable habitats availability induced by the different thermal scenarios. This approach therefore leaves out hydrological alterations, effects of dispersal processes and trophic interactions. In collaboration with the *Conseil Supérieur de la Pêche*, we used data from the *Réseau Hydrobiologique et Piscicole* to prepare probabilistic models taking into account the air temperature at the level of the stations (see Action 1) as well as the hydromorphological and regional context of the river segment considered.

In a first phase, we used the Hierarchical Partitioning method to assess the relative sensitivity of the 13 most common species to local hydromorphology (declivity and wetted width), yearly thermal mean and the particular watershed of the four main French watersheds (regional unit limiting dispersal) in which they are found. For most species, the local declivity of the river segment is a major factor, which determines a succession of taxa along this ecological gradient. All the species predominantly found in the lower sections of the rivers respond positively to an increase of the catchment area, in accordance with the theory of continuous increase in richness along the longitudinal gradient. Temperature is an important contributing factor for two species, Bullhead (28 %) and Lamprey (32 %), and also, but to a lesser extent, for three others, Common Roach (22 %), Trout (20 %) and Bleak (20 %). The hydrogeographic unit is the dominant factor for Bullhead (42 %), and accounts for a fairly high proportion of the total independent contribution in Eurasian Minnow (28 %), Lamprey (27 %), Trout (24 %) and Stone Loach (21 %) – i.e. species characteristic of the upper course of rivers. One of the most interesting results is that the species that are predominantly found in the upstream portions of hydrographic networks stand out by the importance of factors that operate on the regional scale. For Bullhead, Trout, Eurasian Minnow and Planer's Lamprey, the cumulated effects of temperature and range watershed account for between 37 % and 73 % of the explained independent variability, *versus* between 21 % and 35 % for the other species. The low recorded contributions of thermal amplitude suggest that this parameter is not a good descriptor of intra-annual thermal variability, which will need to be taken into account with more precision (monthly variability).

Building on the results obtained above (§ 3.1.2), we attempted to calibrate and validate the models predicting species occurrence, including as predictor variables a description of the physical habitat of the different species and descriptors of inter-season thermal variability. Depending on the biology of the species, we defined four biological seasons. We also worked out that the optimal period on which to base the calculation of the seasonal thermal means associated with each catch covered the five years preceding the sampling, i.e. the life span of most species. The simple seasonal thermal optima were computed for each of the 25 taxa. Multiple logistic regression models including the most significant environmental descriptors were then calibrated and validated (confusion matrix, Kappa test). Twenty-two species were finally satisfactorily modelled.

We then simulated the responses of these taxa to the five climate variability scenarios available in order to assess the potential consequences of a doubling of the atmospheric CO_2 concentration. On average across the five scenarios, severe potential reductions of occurrence over the 792 sampled stations were obtained for 5 species: 4 cryophilous species (Trout, Bullhead, Stone Loach and Planer's Lamprey) and 1 introduced species, Pumpkinseed. For Trout, Lamprey and Stone Loach, the impact worsens progressively as the yearly thermal anomaly increases, with marked reductions in occurrence when anomalies rise above 2°C. For Bullhead, the range is substantiallly affected in the ModMétéo scenario only. In contrast, many Cyprinid species display a continuously positive response with increasing anomaly: Chub, Bleak, Perch, Nase, Common Barbel and Mediterranean Barbel. The Nine-Spined Stickleback has a similar reaction. Potentially important modifications of occurrence are given for all these species, in particular in scenarios with anomalies greater than 2°C (ModCnrmA, ModMétéo). Ca rtographic representations of the expected modifications of the species' ranges are provided for each watershed.

The trends described above would thus substantially affect the fish communities with, overall, a rarefaction of the species that today characterize the upstream segments of the hydrographic network, and an extension of the most rheophilous Cyprinid species into these upstream areas. For numerous species, the weakest anomalies of occurrence would be found in the coastal watersheds draining into the Channel and in Brittany. In contrast, the

occurrence of Trout would be severely affected in the Seine catchment, due to the absence of refuge areas in altitude.

This analysis shows that the potential responses of river fish to climate change vary markedly from one species to the next. It also underlines the necessity to refrain from a direct fish-community-centred approach. In terms of impacts, the effects of climate warming on the distribution and abundance of a large number of taxa appear important and capable of bringing species such as Trout and Stone Loach to such a reduction of occurrences that a risk of extinction may be hypothesized in some watersheds. Other species, and particularly rheophilous Cyprinids, seem likely to benefit, on the contrary, from these modifications.

3.2- Macro-invertebrates
Doledec S. (Lyon1 University-CNRS UMR 5023)

The assessment of the potential consequences of climate change on the macro-invertebrate communities is currently in an exploratory phase that aims to connect faunal and environmental data and to model relationships by taxon. The data used in this project originate from the national monitoring networks (RNB data), the underlying idea being to determine whether such networks and the parameters they integrate are capable of diagnosing climate changes.

Regarding community aspects, the correlation between the macro-invertebrate fauna (presence/absence of families) and environmental data - including local thermal characteristics of water (mean temperature) and atmosphere (temperature variation between the warmest and coldest months), the distance to the head waters, and the classical parameters for monitoring water quality (oxygenation and mineralization) – reaches 0.32 only. This suggests that a significant portion of community variability remains unexplained by the data. Adding altitude to the set of variables brings the correlation to 0.35. In this analysis, mean water temperature and thermal variation contribute to a little less than 50 % in the developed faunal functions, the main factors being linked to the physico-chemical parameters associated with the mineralization processes of organic matter.

The project proposes thereafter a database of logistic models that make it possible to quantify the factors governing the occurrence of 84 macro-invertebrate families commonly found over the 213 reference stations of the RNB (quality A and B). Thirty families are affected by mean water temperature, 11 of which are affected by no other factors (Hydroptilidae, Leptoceridae, Polycentropodidae, Limnephilidae, Caenidae, Dytiscidae, Hydraenidae, Atyidae, Limnoniidae, Dendrocoelidae, Planariidae). The 19 other families are more or less significantly affected by other physico-chemical parameters. For 10 families, the probability of occurrence decreases as water temperature rises. Among them, 5 belong to AFNOR standards high-indicator groups (Perlidae, Odontoceridae, Glossosomatidae, Nemouridae, Sericostomatidae), while the other 5 are not considered as indicator groups (Dytiscidae, Hydraenidae, Empididae, Limoniidae, Planariidae). A total of 10 families (Brachycentridae, Leptophlebiidae, Hydrobiidae, Planorbidae, Glossiphoniidae, Dryopidae, Haliplidae, Tipulidae, Oligoneuriidae, Lestidae) is influenced by atmospheric thermal variations in conjunction with other physical and chemical factors. Perlidae, Potamanthidae, Aphelocheiridae, Gomphidae and Platycnemididae are influenced by the mean temperature of both air and water. The biogeographic factor is involved in 65 % of cases – a fact that underlines the need to spatialize predictions per main hydrogeographic watershed at the national level.

Lastly, the proportion of psychrophilic taxa (preferring temperatures below 15℃) and semivoltine and univoltine taxa was worked out for each study site. Mean water temperature

appears in the models next to the upstream-downstream gradient (psychrophilic taxa) or to mineralization (voltinism) and biogeography. Although the models are statistically significant, their predictive ability remains low. This may be linked to the taxonomical level used in this study – i.e. the family. In this report, the approach is based on computing the proportion of traits recorded from each stations on the basis of the occurrences of the various taxa found in these stations. Another approach, yet untested in this context, would be to predict the probability of occurrence of traits from the probability of occurrence of taxa.

Regarding future developments, the model database proposed may be used to test climate change scenarios concerning temperature changes. The RNB is to this day the only standardized sampling tool encompassing the whole of the French territory. This would make it possible to ascertain whether macro-invertebrate RNB data can help detect a rise in temperatures through the probabilities of occurrence of the invertebrate families usually taken into account.

Action 4: Typology of exotic plant species responses (Adour-Garonne)

4.1- Response of riparian exotic species

Tabacchi E. and Planty-Tabacchi A.M. (LAboratoire DYnamique de la BIOdiversité, UMR C5171 Toulouse).

The objective of Action 4 was to document the responses of riparian and aquatic plant species of the South-Ouest of France to the foreseeable climatic changes. Our hypothesis was that exotic species would benefit, given their dominant thermophily. A first modelling of responses was initiated through logistic models, on the basis of the occurrences of the 50 most frequent populations out of a total of 245 sites distributed along eight rivers and streams of the Adour-Garonne watershed (data from Planty-Tabacchi 1993). The predictor variables selected for this first test were extracted from the '*Ecorégions de la France'* database (Tabacchi *et al*. 1995); their spatial resolution and absolute accuracy are low. One quarter of the 250 tested models did not yield significant results. The others proposed three types of responses: type C (cryophilous), type TT (strongly thermophilic) and type T (weakly thermophilic). With the high resolution and high accuracy of the AQUABIO dataset (Rogers & Lacaze), 100 % of the results were significant as regards mean annual temperature. The three response types already observed also stood out. Warming simulations conducted in +0.5°C steps show that the occurrences of type C taxa, mostly of Asian origin, should not vary significantly in relation to this factor. In contrast, type TT taxa should saturate the current 11-15°C zone on the studied area as from a +1°C rise in temperatures. The occurrences of type T taxa display a variable (in intensity and in space) but significant increase above a +1.5°C rise in temperature. At this point, the models have not been able to discriminate the relative contribution of the temperature factor among the other factors liable to boost the occurrence of species in the future. The example of the analysis of the local and regional distribution of the Ash-Leaved Maple *Acer negundo* underlined the importance of the perturbation regime as co-factor of the potential dominance of this species over indigenous target species (Common Willow *Salix alba*). It can however be predicted that occurrences will very markedly increase for all the species downstream from the foothills of the eight studied systems. This approach is taken further within the framework of two MEDD projects, INVABIO1 and INVABIO2.

An experiment to test the joint effect of vernalization and germination conditions on the success of 5 exotic and 5 indigenous congeneric populations was carried out. It seems that warmer conditions (in the range of the temperatures currently recorded along the Garonne)

do not advantage exotic species over indigenous species, and moreover the former perform better when their seed are vernalized. These preliminary conclusions cannot, however, be generalized to the full set of 700 riparian and aquatic populations of the South-Ouest of France, given the range of temperatures and the limited number of species used in the tests.

4.2- Response of *Ludwigia* spp.
Dutartre A. and Ankrenaz K. (Unité de Recherche Qualité des Eaux, Cemagref, Bordeaux)

According to an analysis of the invasion dynamics in France of *Ludwigia spp* - sub-tropical species particularly invasive in still waters - from bibliographical data and a public inquiry, these species are apparently progressing rapidly northwards. However, under further scrutiny, it appears difficult to isolate a progression logic strictly associated with geographical and climatic factors. Other factors are involved, in particular the possibilities of introduction from the hydrographic network and small garden ponds. The modelling of the responses is still under way as part of the INVABIO2 project of MEDD.

Action 5: The Rhône watershed: Responses to hydrological variability

5.1- Response of macro-invertebrates to the temporal variability of the physical habitat
Doledec S. (UMR CNRS 5023, Lyon1).

The physical habitat of 28 stations of the Doubs watershed were described according to Lamouroux's (1997) procedure. Using discharge time series, we reconstructed the distribution of constraints on the river bed (from F0 to F19) for each discharge decile (from Q1 to Q90). For stations not equipped with a stream gauge, deciles were estimated with the power relation that links the size of the watershed to the discharge. Hydraulic variability was estimated on the basis of the intra-station variability of the river bed constraints' distributions. This new hydraulic variable was integrated alongside the other available physical factors (altitude, declivity, distance to head waters, minimum mean discharge, wetted area at low water). We showed that the assemblages of the three groups of insect species included in this study (Plecoptera, Ephemeroptera and Trichoptera) are largely influenced by the physical habitat. Similarly, biological characteristics of these groups display a structure in relation with the physical habitat. Surprisingly, however, the reconstructed hydraulic variability is not a decisive parameter for the organization of these communities in this particular example. Two hypotheses may be proposed. The first concerns the type of network studied: the prospected area is in a karstic region, and the discharge and catchment size estimates may be underestimated. The second concerns the long time gap that occurred between the faunal samplings and the physical parameter samplings. We were careful to only take into consideration stations that had not undergone any morphological modifications, but we cannot fully exclude the possibility of interventions on the watersheds that may have affected the flows.

5.2- Hydraulic preferences of benthic macro-invertebrates
Doledec S. (UMR CNRS 5023, Lyon1) and Lamouroux N. (UR Hydroécologie Quantitative, Cemagref- Lyon)

This project was entirely based on pre-existing data from 580 samplings from 9 German rivers over two or three seasons. Each of these samples comprises a faunal list and

corresponds to the value of an FST hemisphere, which estimates the hydraulic constraint on the river bed at the exact sampling site. Three mixed-effects nested non-linear models were used to construct and test the hydraulic preference curves of 151 taxa. The mean model per taxon explains 25 % of the variation in density between sampling campaigns. This figure reaches 20 % and 48 % respectively with independent data sets. Species thus exhibit contrasted responses to the variation of FST hemisphere values. There is a curvilinear relationship between the mean preferences of the taxa and the variance of these mean preferences (R2 = 0.68). This relationship indicates that the amplitude of the hydraulic niche is narrow for extreme values of FST. Mean preferences are relatively stable from one genus to the next. At the family level, wide ranges of variations (e.g. Baetidae) and many overlaps are observed. A strong relationship exists between the mean preferences of the taxa as extracted from the data set used for constructing the hydraulic preferences curves, and those from the independent data sets (R2 = 0.70 and R2 = 0.62, respectively). No significant relationship was found, on the other hand, between the hydraulic niche amplitudes of the taxa common to all data sets. The spatio-temporal variability of the hydraulic preferences is significant. All taxa included, the most complex model - per taxon and per campaign - explains 38 % of the intra-campaign variance of densities. Out of these 38 % of explained variance of intra-campaign variations, 2/3 are linked to the mean preferences of the taxa and 1/3 to the inter-campaign variability. The hydraulic preferences expressed by the per taxon and per campaign model exhibit a significant taxonomic effect (R2 = 0.5). In contrast, the other variables (season, site, mean sampling campaign FST, mean density of a taxon throughout the campaign), when integrated as cofactors in the ANOVA, do not increase significantly the percentage of explained variance.

The results of these two approaches may be used to test the impact of the climate changes described in the different climatic scenarios. The models developed for the species may moreover be extended to include their biological characteristics (such as size, physiology, mobility, etc.).

5.3- Ecological sensitivity of fish to hydraulic anomalies
Lamouroux N. (UR Hydroécologie Quantitative, Cemagref- Lyon)

This contribution was precisely focused on the impact of hydraulic changes (in stream velocity, water depth, etc.) on fish. The hydraulic aspect constitues a major characteristic of the habitat of aquatic species; it determines habitat selection, and evolutionary strategies in the longer term. There is another reason for focusing on climate-related hydraulic changes: validated quantitative models already exist for this catchment, that link fish communities to hydraulic conditions – models whose uncertainty can be estimated. Our approach is based on the coupling of a series of models linking biological anomalies to hydraulic anomalies on one hand, and, on the other, hydraulic anomalies to hydrological anomalies pinpointed by GICC-Rhone under the atmospheric CO_2 doubling scenarios. The first outcome of this modelling exercise is that we are now in a position to carry out the quantitative exercises in modelling the biological impacts of large-scale changes in river discharge. This was not possible a few years ago, when the necessary habitat models were too complex and not fully validated. It must be stressed, however, that the recourse to ‘aggregated’ biological impact models must not make one overlook the fact that they assume the unaltered continuation of biological processes, on the scale of the individual, which are also liable to be affected. This is the ‘danger’ of the simplified habitat models we use on the scale of river segments.

If one considers plausible a 30 to 40 % reduction of the dry period monthly discharge over the watershed (several scenarios agreeing on this possibility), then a 20 % mean reduction in the proportion of running-water species is also plausible. It could concern in particular the north-north-east area of the studied watershed. Without being utterly ‘catastrophic’, this trend

could reinforce the general regression of these species in Europe (in particular Nase, Grayling, Dace and Barbel) due to the engineering of water courses.

5.4- Network structure and fish diversity
Pont D. and Grenouillet G. (UMR CNRS 5023, Lyon1).

In a test-catchment (the Haute-Saône) fully documented as regards physical and biological aspects, we showed that the local species richness (LSR) of fish assemblages depends on local habitat conditions and on the spatial positioning of the stream. We studied the relative effects of local habitat factors and of spatial factors (upstream and downstream) on the species richness. Among the local habitat variables, the width and declivity of the water course are the only ones to significantly affect LSR. Spatial factors are also involved in the distribution of LSR and induce a spatial autocorrelation – a fact that reveals the existence of 'contagious' biotic processes structuring fish communities. We were not able to test, however, the prediction according to which low-order streams that flow directly in much larger rivers should be more species-rich. The spatial autocorrelation only concerned downstream tracts (streams and rivers of 4^{th} to 7^{th} order), suggesting that the relative importance of local habitat and biotic processes could depend on the position along the longitudinal gradient. In the context of our research, these findings attest that the upstream-down migration processes are less important than the downstream-up movements and that their influence is weaker near the catchment's head waters. This would tend to intensify the potential magnitude of the global warming impact on the upstream fish communities. This process should thus facilitate the colonization of intermediate zones of the hydrological network by rheophilous Cyprinids, to the disadvantage of small stream (rhitronic) species such as Trout, Bullhead and Stone Loach.

Action 6: The Seine watershed regional project – Testing the sensitivity to hydro-climatic variables of decision-tree models for the prediction of fish fauna
Boët P., Gorges G. and Ledouble O. (U.R. Qualité et Fonctionnement Hydrologique des Systèmes Aquatiques, Cemagref Antony)

Models predicting the presence or absence of the most common fish species in the Seine watershed were set up using a non-linear and robust statistical method called a decision tree.

These specific models were spatialized with a geographic information system (GIS), which allowed the visualization of the results on the scale of the entire hydrographic network.

Predictions are made according to the characteristics of the water courses. The models are constructed giving precedence to existing data. These come directly from databases (Corine Land Cover, banque Hydro, etc.) or are derived or calculated, by the GIS and/or a digital terrain model (declivity, watershed surface area, sinuosity). Performances are assessed with ROC curves - which are now increasingly used in the field of medical diagnoses - with good results overall. However, among the various variables considered, the hydro-climatic variables (temperature and discharge) do not produce a statistically significant increase in performance.

Temperature being nonetheless selected in the trees of several species, a simulation of the mean water level changes was carried out, which indicated small changes only in species occurrences,as predicted by the models when this parameter alone varies.

Action 7: Socio-economic issues – Response of the actors
Combe P.-M. (UMR 5601. Laboratoire d'Economie et de Gestion, Bourgogne University)

The findings from the Action 3 simulations concerning the spatial distribution of fish species in French rivers in response to given global warming hypotheses left a number of 'non-technical' questions unanswered. These pertain to three concatenated levels:

- How will fish management policies adapt? Curatively? Preventively?
- How then will fisheries management policies adapt? This question derives from the first one, but only in part: at least locally, a situation may include a 'fish' issue without a 'fishing' issue and vice-versa.
- What would be the socio-economic consequences of these changes, or of their being taken into consideration as an adaptative measure (with a more or less curative or preventive approach)? This question in turn derives from one and/or the other of the two previous interrogations.

These questions, as well as all the sub-questions that may arise from them, concern the social sciences, mainly through the action taken by the various parties involved and the confrontation of benefits and costs (to the society as a whole and to its various components) associated with alternative action programmes.

On the other hand, it is important to prevent the tendency of non-scientists to extract from such results simple 'predictions' about economic losses and the ensuing social traumatisms, obscuring implicit hypotheses on the adaptive behaviour or response of individuals, economic actors and fisheries managers, aquatic habitats and various public policies.

In the first phase of this socio-economic study, a conceptual framework was devised in order to identify systematically, in every case, the categories of issues (fish issues, fishing (halieutic) issues or other derived economic issues), together with their interrelations. It associates a systemic vision and a joint procedure (economist-ecologist) in regard to problem identification, inspired by the EPA recommendations on the economic evaluation of ecological benefits, to which the fish/fisheries issues of climate warming may be assimilated.

The second phase of the project, which aimed to localize and prioritize the major problem areas in France, combining issues related to fish populations and to fisheries, has not been completed. However, the analysis per département of fish-context data allowed us to draw a reference map of fish populations in France, not incorporating the climate hypothesis, with the idea of integrating, in the calculation of contexts, the potential impacts of climate warming. If this project was to be carried through, it would lead the way to the taking into consideration of fish and fisheries issues in economic decisions through PDPG (*Plan Départemental pour la Protection du milieu aquatique et la Gestion des ressources piscicoles*).

In the same line, we suggest that applied economic research should be put on a more permanent footing, in connection with the various stages of the DCE (French Framework Directive on Water) implementation.