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Using genetic with stable isotope analyses to investigate hybridization between Atlantic salmon, sea-run and stream resident brown trout in a small stream

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► To cite this version:

Jean-Marc Roussel, Katia Charles, Jean-Luc J.-L. Baglinière, René R. Guyomard, Dominique D. Ombredane. Using genetic with stable isotope analyses to investigate hybridization between Atlantic salmon, sea-run and stream resident brown trout in a small stream. *Fish and Diadromy in Europe: Ecology*, Mar 2005, Bordeaux, France. pp.1. hal-02833949

HAL Id: hal-02833949

<https://hal.inrae.fr/hal-02833949>

Submitted on 7 Jun 2020

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Scientific Institute of the Flemish Government



Institute for Forestry and
Game Management



Fish and Diadromy in Europe

“Ecology, management and conservation”

Bordeaux, France



29th March – 1st April, 2005

Caroline Geeraerts & Hilde Verbiest

IBW. Wb.V.C.2005.82

Report of the conference

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“Ecology, management and conservation”

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Introduction

The conference about 'Fish and Diadromy in Europe' took place at the Mercure Cité mondiale in Bordeaux, France, from 29th March - 1st April 2005.

The aim of this symposium was to synthesize knowledge on diadromous fish by facilitating: presentation of original results from different disciplinary fields and/or a multi-species approach; synthesis at regional and continental scales; links between science and management or policy.

The program focused on the following themes:

- Biogeography at regional and European scales (relationships between characteristics of drainage basins and the presence of diadromous fish, natural or anthropogenic evolutionary biology, spatial strategies)
- Diadromous fish in the ecosystems (competition, facilitation, predation, role in the dynamics of the ecosystems)
- Life history strategies and adaptations (homing and straying, migrations, analysis of trade offs)
- Man and diadromous fish
 - Fisheries, socio-economic and heritage importance, historic evolution.
 - Impact of human activities and diadromous population viability, sentinel species of water quality and ecosystem connectivity.
 - Conservation and diadromy, theory and concepts, application to diadromous fish, specialized engineering, decision support system.

This symposium concerned scientists and managers (governmental, region, NGO) interested by diadromous species. There were three days of scientific session: lectures, oral communications and a poster session.

Organising committee

Jean-Luc BAGLINIERE (INRA, Rennes, France)
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Sylvie DUFOUR (CNRS-MNHN, Paris, France)
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Karin E. LIMBURG (State University of New York, Syracuse, USA)
Robert Mac DOWALL (NIWA, Christchurch, New Zealand)
Etienne PREVOST (INRA, St Pée sur Nivelles, France)
Ralph THIEL (German Oceanographic museum, Germany)
Guido VAN DEN THILLART (University of Leiden, The Netherlands)
Patrick WILLIOT (Cemagref, Bordeaux, France)

Exhibitors



CONSEIL REGIONAL



AQUITAINE



Program

Monday March 28th

- beginning of the registration in the main lobby of the "Cité mondiale".

Tuesday March 29th

- Registration - (continued)
- Welcome and Opening session (Organizing committee, VIP)
- Introductory lecture: **The conditional nature of diadromy** by Pr Julian Dodson (Université Laval, Québec, CANADA)
- **Session I "Biogeography at Continental and Regional scales"**
Chairpersons: Philippe Keith (National Museum of Natural History, Paris) and Robert Mc Dowall (National Institute of Water and Atmospheric Research, New Zealand)
- **Session II "Diadromous fish in Ecosystems"**
Chairpersons: Ralph Thiel (German oceanographic museum, Germany) and Pierre Dumont (Natural Resources Ministry, Qc, Canada)
- **Session III "Life history strategies, tactics and adaptations 1"**
Miran Aprahamian (Environment Agency, UK) and Patrick Williot (Cemagref, Bordeaux)
- Social Poster session

Wednesday March 30th

- **Session IV "Life history strategies, tactics and adaptations 2"**
Chairpersons: Karin Limburg (State University of New York, Syracuse, USA) and Etienne Prévost (INRA, St Pée sur Nivelles, France)
- **Session V "Life history strategies, tactics and adaptations 3"**
Chairpersons: Bror Jonsson (NINA, Norway) and Guido Van den Thillart (University of Leiden, The Netherlands)

Thursday March 31th

- **Session VI "Human activities and Diadromous fish 1"**
Chairpersons: Henriette Jager (Oak Ridge national laboratory, USA) and Hans Lundqvist (SLU, Suède)
- **Session VII "Human activities and Diadromous fish 2" (Management advice)**
Chairpersons: Pedro Almeida (Oceanographic Institute, Lisbon, Portugal) and Willem Dekker (RIVO, The Netherlands)
- Conference closing session (organizing committee, VIP)

Friday April 1st

- **Session VIII: MINI Symposium** "Estimation of the Reproduction capacity of European eel".

Presentations:

Session I “Biogeography at Continental and Regional scales”

1. Diadromy, history and ecology: a question of scale

Dr Robert McDowall

National Institute of Water and Atmospheric Research, Christchurch, NEW ZEALAND

The existence of diadromous migrations has significant implications for understanding a broad series of biogeographical and ecological questions, and these apply across a broad range of spatial and temporal scales. Understanding these questions is important for interpretation of patterns in the historical and ecological biogeography of fish species, as well as in community ecology and conservation. Diadromous species tend to be widespread; they exhibit limited genetic structuring owing to high levels of gene flow; however, on the contrary, landlocking of diadromous populations often leads to speciation, increasing diversity; diadromy has an important role in facilitating restoration of populations after perturbation; and there are implications for the assembly of fish communities in river systems. This paper explores these implications.

2. Evolutionary history of lamprey paired species, *Lampetra fluviatilis* (L.) and *Lampetra planeri* (Bloch) inferred from mitochondrial DNA: timing and mode of divergence

Ms Rute Espanhol, Bernardo R. Quintella, Pedro Raposo Almeida & Maria Judite Alves

Museu Nacional de História Natural da Universidade de Lisboa and Instituto de Oceanografia, Lisbon, PORTUGAL

A remarkable trend in the evolution of lampreys (Petromyzontidae) is the occurrence in most genera of, Spaired species~T (Zanandrea 1959) or , Ssatellite species~T (Vladykov & Kott 1979), in which the larvae are morphologically similar but the adults adopt different life history types, namely parasitic anadromous (*Lampetra fluviatilis* (L.)) vs. non-parasitic freshwater resident (*Lampetra planeri* (Bloch)). The present work examines the phylogeography of the European paired species *L. fluviatilis* and *L. planeri*, in an attempt to elucidate species pair evolutionary history. We studied sequence variation in 2002 bp of almost complete cyt b and ATPase 6, 8 mitochondrial genes in 62 individuals from 19 populations of the paired species across the species range in Europe. Phylogeographic and Nested Clade analyses were used to elucidate the species pair evolutionary history. Alternative evolutionary scenarios were evaluated: multiple occurrences of nonanadromous/nonparasitic brook lamprey may result from independent divergences from the anadromous/parasitic river lamprey, with repeated loss of anadromy; or resident lamprey may be monophyletic, with vicariant divergence affected by drainage evolution. The study revealed three main clades: (1) Sado clade (Iberian Peninsula); (2) Vouga clade (IP) and (3) remaining populations of all other basins (Europe). The results from phylogeographic methods and mismatch and nested clade analysis were largely consistent providing strong support for the polyphyletic origin of *L. planeri* and suggesting that the last glaciation has played an important role in shaping the pattern of genetic variation. There are evidences of a recent range expansion from a Pleistocene refuge in the Iberian Peninsula. Colonization of Northern Europe appears to have been a recent event. Using a range of mtDNA molecular clock rate of 0.8% - 2% per million years (Martin and Palumbi, 1993; Cantatore *et al.*, 1994; Machordam & Doadrio 2001) the divergence of the Sado population and European populations dates back 0,65 - 2,7 mya, Sado and Vouga populations 0.73 - 2.9 mya, and Vouga and European populations 0.36 - 1.4 mya. Whether or not these divergence time estimates are precise, the results suggest that prior to the last glaciation, populations of *L. planeri* already existed in IP, which contradicts the Hardisty & Potter (1971) statement that *L. planeri* is a recent species with an origin explained by the recent glaciation. The unique genetic architecture of *Lampetra* populations present in the Portu-

guese basins, namely of Vouga and Sado, should be protected and management measures will be required to warrant the persistence of these populations in IP.

3. Are *Lampetra fluviatilis* (L.) and *L. planeri* (Bloch) two species? The answer using genetics and ecological implications

Dr Maria Urdaci, Pierre Elie, Catherine Taverny & Anne Marie Elie

Enita, Gradignan, FRANCE

In the south-west of France, larvae of *Petromyzon marinus*, *Lampetra fluviatilis* (migrating lampreys) and *L. planeri* (sedentary lamprey) are commonly found in the same watershed indeed even on the same river. During this eco-phase they attend the same types of habitat. In the case of the genus *Lampetra*, distinguishing the species isn't possible before an advanced stage of metamorphosis. In order to gain better knowledge of their ecology, it is necessary to be able to identify them during the larvae eco-phase. To do so, genetic analysis were carried out on individuals identified thanks to body characters (adults) and to habitat isolation with sites blocked by weirs (*L. planeri* larvae). Lampreys issued from tributaries of the lower part of the Gironde-Garonne-Dordogne watershed. A first quick genotyping test was developed (results in less than 48 hours). Thanks to an analysis of the mitochondrial B cytochrome, using PCR-RFLP, this test allows us to differentiate the gene coding for *Petromyzon marinus* from the one coding for the different *Lampetra* species. After analysis of an even more variable mitochondrial region, *L. planeri* and *L. fluviatilis* do not appear as two species but as morphotypes of the same species. In the same manner it is reminded that *Salmo trutta* presents sedentary and migrating forms. The authors believe that this phenomenon exists also for *Lampetra* and that the species *fluviatilis* is only the migrating form of the „*Splano fluviatilis*“ complex. A hypothesis of biological similarities is put forward between *Lampetra fluviatilis* and *Salmo trutta* concerning : the partial heritability of the migratory characteristic, the influence of the growth parameter on the relative fecundity observed as of the larval stage and on the migration determinism. The importance of gregariousness in the larval habitats is also put forward as an additional factor which initiates the evolution towards the amphihaline migration form. Among the principal work prospects, the reproductive isolation of the populations of the two *Lampetra* forms has to be verified. In any case, the management of the populations of both *Lampetra* forms implies that the eco-type *L. fluviatilis* must be maintained, therefore access to its habitat situated at the beginning of watersheds, amongst other places, must be restored.

4. Colonization potential of a coastal region by migratory brown trout (*Salmo trutta* L.); the case of the Kerguelen Islands (TAAF). 1) Colonization dynamics and environmental conditions

Mr Patrick Davaine & Edward Beall

INRA, Saint Pee sur Nivelle, FRANCE

Brown trout is a facultative migratory species which may present within the same population a high variability in behaviour, from sedentarity to far-ranging oceanic migration. This behavioural variability allows the optimal exploitation of fragmented environments and the exploration of new streams thanks to the straying of some individuals during their marine migration, even though homing is the general rule. These deviant migratory behaviours have allowed the species to colonize streams after glacier withdrawals at the end of the last ice age. In spite of recent progress in population genetics, it is difficult to appreciate a posteriori the speed of trout colonization in those areas left virgin, as well as the environmental factors which adjusted it. The Kerguelen Islands, characterized by a cold temperate climate, possess a network of streams free of fish but with all the essential attributes of salmonid rivers. The well-documented limited introduction of brown trout in 1955 and 1958 in a small number of rivers, and the following colonization phase, provide an interesting model by analogy with the post-glacial colonization phenomena. The demographic study of introduced populations, individual tagging and sampling in neighbouring streams have shown the discontinuous pattern of colonization in space and time as well as the important role of geomorphological characteristics of streams and coastlines in these phenomena.

5. Colonization potential of a coastal region by migratory brown trout (*Salmo trutta* L.); the case of the Kerguelen Islands (TAAF). (2). Genetic structure of the populations after a dispersion and colonization phase

Dr Sophie Launey, Patrick Davaine, René Guyomard & Géraldine Brunet
INRA, Jouy en Josas, FRANCE

Salmonid populations in Kerguelen Islands are characterized by (1) a simple history of introduction, (2) no or very little anthropic influence (restocking, nuisance, overexploitation), and (3) a rather thorough demographic monitoring since the first introductions. The Kerguelen Islands archipelago is thus a favourable model ecosystem for the studies of genetic and behavioural variability of salmonids, and answer questions that can be difficult to study in European ecosystems, more complex and subject to more perturbations. Our work aims to study colonization patterns (migration routes, origin of source populations, time and extent of migratory flows) of the brown trout (*Salmo trutta* L.) after an introduction in a environment previously void of fishes. More precisely, we studied genetic variation (at 10 microsatellite loci) of 19 populations of the Courbet peninsula, where the species, introduced in 3 rivers only, has colonised the whole water system in the span of 40 years. Our results have shown that in spite of a limited numbers of introduction, brown trout populations have maintained a genetic diversity comparable to what is found in hatchery or wild populations in Europe. Besides, these populations have diverged, and the current pattern of genetic differentiation follows a model of isolation by distance. The peninsula can be divided into two different geographic groups, with different characteristics of colonization and migration patterns: (i) a zone of recent colonization (North), where migrations seem slower and the populations are still in the expansion phase and highly differentiated, and (ii) a zone of more ancient colonization (East), with higher migratory flow and genetically homogeneous populations. This division is linked to environmental parameters, such as relief, hydrology or food resources, that seem to have an impact on the dispersion ability of the species.

6. The return of wild salmon to the River Gudenå

Mr Christian Dieperink
WaterFrame, Ry, DENMARK

The native salmon of the River Gudenå became extinct around 1930, due to the construction of the Lake Tange hydropower reservoir. Since then, a fish ladder was constructed and several times improved, however without apparent success. During 2000-2002 the commercial fisherman at Lake Tange reported the unintentional bycatch of several hundred salmon. On that background, the hydropower company, Gudenaacentralen, launched an investigation on the ascent and spawning of salmon upstream Lake Tange. The result was the discovery of a newly founded population in autumn 2004. The small population consists of two-three hundred individuals, 13-21 cm long parr that have colonized the lower 6-7 kilometres of the River Tange, a small tributary to the River Gudenå. Genetic analysis of the salmon parr revealed that they owe their presence to spawning by stray salmon originating themselves from stockings of fish from the Swedish River Ätran. The presence of wild salmon above the weir at the Tange hydropower station documents to the high standards of the stream habitat quality in River Tange, and to the functionality of the fish ladder at the dam, yet still perhaps suboptimal. The function of the fish ladder at Tange was in autumn 2004 investigated with an automated fish counter, a so-called Riverwatcher. A total of 147 salmonids above 45 cm migrated upstream through the fish ladder, with five salmon above 100 cm as the largest individuals. The upstream fish passage through the Tange fish way is thereby three times higher than the passage that was last recorded in 1994-95.

7. Return of the twaite shad *Alosa fallax* (Lacépède, 1803) in the Baltic Sea: historical importance, intermediate decline and recent recovery of the population

Dr Ralf Thiel, Philip Riel, Renate Neumann, Helmut M. Winkler, Uwe Böttcher, Tomas Gröhsler & Dietmar Lill

German Oceanographic Museum, Stralsund, GERMANY

The status of twaite shad in the Baltic Sea was studied based on the analysis of the following sources of data: actual research fisheries with otter trawls, recent records from commercial and recreational fisheries, historical records from ichthyological museum collections, historical commercial catch statistics, past and present relevant publications and grey literature. About 40 % of the historical local records of twaite shad were estimated in ICES subdivision 24, whereas about 20 % were registered in subdivision 26. *A. fallax* was mainly distributed in the Southern Baltic within the areas of Pommeranian Bay and Pommeranian coast, Szczecin Lagoon, Bay of Gdańsk, Vistula Spit, Vistula Lagoon, Kuržiu Spit and Kuržiu Lagoon. Twaite shad was an important commercial species in those areas during the last quarter of the 19th and the first half of the 20th century. The mean annual catch of twaite shad amounted to 90 982 kg for the entire Southern Baltic Sea between 1891 and 1960. About 48% of the mean annual catch were contributed by subdivision 26, comprising the areas of Gdańsk Bay, Vistula Lagoon/Vistula Spit and Kuržiu Lagoon/Kuržiu Spit. Seasonal commercial catches of twaite shad showed maximum values from May to July and peaked in June. The annual catches of twaite shad in the Southern Baltic declined sharply in the 1950s. *A. fallax* was only occasionally caught in the Baltic Sea region until the mid 1990s. The Baltic population of twaite shad has been increasing again since the middle of the 1990s after about 40 years of decrease or absence respectively. From May 2003 until November 2004, 38 individuals of twaite shad were recorded at 14 different localities in the Exclusive Economic Zone of Germany northeast of the Rügen Island as well as in the Pommeranian Bay and in the Szczecin Lagoon and its adjacent waters. The records from the Szczecin Lagoon and adjacent waters comprise mature adult individuals and date from May to July. Additionally, adult and juvenile individuals of *A. fallax* have been observed more frequently in Lithuanian and Polish waters of the Southern Baltic Sea since the mid 1990s.

8. Aspects of Allis shad (*Alosa alosa* L.) and twaite shad (*Alosa fallax* lacepede) biology in four Irish S.A.Cs.: status, evidence of spawning and implications for S.A.C. designation

Dr James King & William Roche

Central Fisheries Board, Swords, REPUBLIC OF IRELAND

Four Special Areas of Conservation (SAC) have been designated in the Republic of Ireland for twaite shad, *Alosa fallax* (Lacépède), based on recent historical information on spawning activity - the estuarine reaches of the Munster Blackwater, the Suir, the Barrow-Nore and the Slaney. The spawning status of some of these populations is considered to have declined substantially in recent years and no known spawning areas of allis shad, *Alosa alosa* (L.), are known for Ireland. Data is presented confirming the presence of both allis shad and twaite shad in all four SACs. The majority of the material has come as by-catch from inshore commercial salmon netmen. Very limited amounts of data have come from structured scientific sampling. Angling information is the principal source of material from the R. Barrow. Examination of gonad material of allis shad indicates some degree of readiness for spawning as well as spawning having taken place. Gonadosomatic index (GSI) values of 18% and 22% have been recorded in the July period for individual allis shad from the upper estuaries of the R. Slaney and R. Suir, respectively, with both fish displaying condition stage V or VI (after Kesteven 1960). Comparable GSI data from the R. Barrow for twaite shad in the May spawning period (2000-2002) had mean GSIs of 13.7 - 15% with maxima in the range 21 - 28%. Low GSI values have been recorded from other allis shad in the June - July period displaying gonad condition varying from stage III (immature) to stage VIII (spent). These findings point to a possibility that allis shad do engage in spawning activity, whether mono-specifically or with twaite shad. The possibility of the latter is supported by gill raker count data presented. In addition to clearly defined value ranges for twaite and for allis, the gill raker counts also identified a series of fish with intermediate counts. These counts may point to a degree of hybridisation. The occurrence of occasional twaite shad, in the data presented, in mid-late summer with high GSI values may be indicative of fish not spawning in May, as is the norm in the R. Barrow spawning location, and may indicate that some ripe twaite shad are available later in the summer when allis shad are ripening.

Presentations:

Session II “Diadromous fish in Ecosystems”

1. Increased possibilities for diadromous fish populations in the tidal Scheldt estuary (Belgium)

Dr Joachim Maes, Maarten Stevens, & Johan Coeck

Katholieke Universiteit Leuven, Leuven, BELGIUM

The River Scheldt, a heavily urbanized and industrialized river draining into the Southern Bight of the North Sea, is probably the dirtiest river in Europe. The total catchment area of the river is about 21,500 km², extending over densely populated and industrialized areas of France, Belgium and The Netherlands. The recent history of the river is characterized by serious pollution and considerable reductions of, mostly, intertidal habitats such as mudflats and salt marshes. Domestic and industrial wastewater emissions have critically affected water and sediment quality and caused virtually anoxic and hypertrophic conditions in the tidal freshwater and low-salinity zones of the estuary in the 1970s. Since the mid 1980s, the river and its tributaries have benefited from gradually increased water quality, resulting in improved conditions and possibilities for estuarine resident and transient fish populations. In particular, we focused our attention on the recovery of diadromous fish populations, especially in tidal freshwater habitats. We used the bioenergetics model approach to generate spatially explicit estimates of growth potential for different species using, in essence, abiotic conditions as model input. Under the assumption that habitat quality can be measured by growth rate potential, the model shows the importance of different environmental variables affecting habitat quality. In spring, fast increasing temperatures in upstream riverine habitats may be beneficial to the growth of young fish of both anadromous and catadromous populations, provided that the levels of dissolved oxygen further increase, while in summer and autumn, habitat quality is more favourable in the brackish water regions. Model predictions of optimal habitat quality were tested against an independent fish dataset consisting of various field data, collected in the estuary using fyke nets. First, data was subjected to different regression techniques to produce distribution maps of diadromous fishes throughout the estuary. Model predictions and field observations matched closely, so the model may be a helpful tool to better define and protect essential fish habitats that are now affected by various human-induced stressors.

2. The place of the diadromous fish assemblage in the estuarine food web - The Gironde estuary as a case study

Dr Jérémy Lobry, Stéphanie Pasquaud & Maria José Costa

Cemagref of Bordeaux, Cestas, FRANCE

Diadromous fish have ecological, economic and sociological importance. That is probably particularly true in an estuarine context. Indeed, they are amongst the most characteristic and valuable components of European estuarine fish communities even when they don't constitute the major part of the ichthyofauna. Most of them are of interest for fisheries but most of them are also endangered and vulnerable. This contributes to make this resource participate in a large way to the high production and also high heritage importance of estuarine areas. This situation is particularly striking in the Gironde estuary. For several reasons, it constitutes a major ecological stake. First, the Gironde estuary is the biggest in France and one of the largest in Europe. Moreover, it appears to be the European estuary with the largest migratory amphihaline fish assemblage. 11 diadromous species still exist in the Gironde. They represent 15% of the species and they are amongst the most frequent species of the total fish community. But what is exactly the place of these species in the functioning of the whole estuarine ecosystem? This question is partly answered in this study by considering their place in the food web. The trophic network of the Gironde estuary is described using an Ecopath model which allows us to quantify the part of the total trophic flows in the ecosystem that is due to diadromous fishes. It fluctuates according to the season. At an annual scale, flows due to diadromous fish represent just less than 1% of total flows and nearly 5% of flows due only to fish. It

is quantitatively quite little but probably not qualitatively negligible. In fact, the diversity of diadromous fish in terms of diet compositions and trophic levels allows them to notably take part in the transfer of organic matter along the food chain according to the season and to the availability of trophic resources. The case of the Gironde estuary can be compared, for part, to the case of the Tagus estuary through the study of similarities and differences in diadromous fish diet compositions.

3. Hyporheic community respiration in river sediments and egg-to-fry survival of sea trout in tributaries of the River Rhine, Germany

Dr Detlev Ingendahl, Dietrich Neumann & Martin Pusch

State Inland Agency for Ecology of North Rhine-Westphalia, Kirchhundem, GERMANY

Hyporheic community respiration, which is the oxygen consumption of the biofilms colonizing the sediments of gravel bed-rivers, and egg-to-fry survival were studied at spawning grounds of sea trout (*Salmo trutta*) in tributaries of the River Rhine, Germany. During the spawning season in early winter freshly fertilized eggs of sea trout were exposed into the gravel bed using Whitlock-Vibert-boxes. During the incubation of the eggs physiochemical parameters of interstitial water, especially dissolved oxygen, were determined regularly. Survival of exposed trout eggs was controlled during the eyed stage, at hatching and at time of emergence of trout fry. Hyporheic community respiration was measured using sediment-filled tubes buried into the sediments in the vicinity of the egg boxes. After transport to the laboratory, oxygen consumption of the biofilms colonizing the tubes was monitored in a recirculating flow-through system. Hyporheic community respiration, interstitial water quality and sediment particle distribution was finally correlated to egg-to-fry survival of incubated sea trout egg. This analysis was performed to identify the consequences of human impact (sediment and nutrient delivery) on the functioning of the hyporheic zone in spawning tributaries of the River Rhine. It was found that not only the sediment particle distribution but additionally the intense hyporheic respiration influenced on hyporheic oxygen levels and egg-to-fry survival of sea trout. The findings are of particular relevance to explain poor spawning habitat quality for sea trout populations on the background of current restoration efforts for Atlantic salmon in the River Rhine.

Presentations:

Sessions III, IV and V “Life history strategies, tactics and adaptations”

1. Movement and dispersal in young stages - examples from catadromous and anadromous species

Dr Agnès Bardonnnet, Philippe Gaudin & Jean-Luc Baglinière

INRA (Bordeaux), St Pée sur Nivelle, FRANCE

Dispersal of young fish from the spawning area to the growing area is not necessarily an immediate phenomenon and different phases of movement can be brought out. A first movement will mainly disperse fish from the spawning area. In several anadromous species, this early dispersal is observed just when fish reach the water column at hatching or emergence time. This first dispersal presents different characteristics (in terms of habitat change, timing, distance of dispersal, proportion of fish concerned) according to species. In catadromous species like eel what happened in the sea is highly speculative, but a parallel can be drawn with sea current dispersing leptocephalus larvae from the spawning area. A second movement may occur, mainly due to a lack of comfort (sensu Balchen 1976) resulting from competition for resources (food, cover) or from seasonal constraints. The next movement corresponds to the real estuarine migration of young stages, and occurs when fish went across the estuary. It corresponds to a mass movement at a more or less definite time of the year. This movement can include a waiting phase in the lower estuary or in a bay in the case of some anadromous species, and at the tidal limit in the case of eels. In anadromous species this movement drive the fish to the marine area which offers homogeneous and constant environmental conditions. In the highly heterogeneous and variable habitat reached by eel, growing opportunities depend highly on the further movements realized by eel throughout the basin. It appears that in some anadromous species such as salmon and trout some individuals do not realize the seaward movement and grow up to maturation in stream conditions. These fish are usually smaller, except if environmental opportunities such as productive lakes are connected with their juvenile rearing area. The occurrence of this sedentary behaviour is usually skewed towards males in salmonids. In eels, recent results have put forward that a significant proportion of eels grew in estuary or on the sea coast. According to the higher productivity of these areas, these eels grew faster and may reach maturity earlier in their life span than stream eels.

2. Temporal and spatial dynamics of the smolt migration of Atlantic salmon (*Salmo salar*)

Ms Catherine Brisson-Bonenfant, Julian Dodson & Jean-François Bourque

Centre interuniversitaire de recherche sur le saumon Atlantique, Quebec, CANADA

The overall objective of this project was to document the influence of body size on the timing and pattern of smolt outmigration in Atlantic salmon. In the Ste-Marguerite R., Québec, smolt migrates to sea from mid-May and the end of June between 2 and 4 years of age. We formulated and tested 3 hypotheses concerning the importance of growth on the decision to migrate acting at different temporal and spatial scales. We tested the hypotheses that smolt represent the largest fish of their cohort, that smolt migrating late in the season do so as they are too small to initiate migration early in the season and that age and size at the beginning of downstream migration is lower upstream than downstream. Smolts captured at the end of outmigration were bigger than smolts captured at the start of outmigration. However, smolt captured at the end of outmigration were smaller at spring annulus formation (inferred from backcalculation) than those that migrated early. The body length of 2 and 3-yr-old smolt captured in 2003, backcalculated to the previous year, exceeded that of 1 and 2 yr-old parr, respectively. Furthermore, the size of 2-yr-old smolt captured in 2003 was bigger than that of 2-yr-old parr captured the same year but that did not undergo smoltification. Spatially, condition factor was smaller downstream whereas mean body length of smolts was smaller upstream. Growth rate was independent of position in the river. The sex ratio

was always biased towards females and there were always more 3-yr-old smolt than 2 yr-old smolt. We conclude that the existence of a critical body size for outmigration structures both temporally and spatially the outmigration. The decision to outmigrate is size selective, with the largest members of parr cohorts undergoing smoltification. Smaller smolt delay outmigration to gain body size before leaving the river. Smolt from upstream initiate migration at smaller sizes, possibly related to increased opportunities for growth before entering the marine environment. The final stages of metamorphosis, indicated by decreasing condition factor, apparently occur near the mouth of the river. Finally, observations in late fall indicate significant downstream migration occurs before the winter proceeding outmigration.

3. Inputs of behavioural experiments to the individual-based modelling of glass eel estuarine migration

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Understanding glass eel estuarine migration is now a scientific and management challenge for the eel resource which is declining worldwide. We choose to develop a dual approach combining behavioural experiments and individual-based modelling to investigate field migration dynamics. The model couples a hydraulic model of the Gironde estuary with a behavioural module for individual movements. The behavioural module searches to mimic a selective tidal stream transport (STST) based on an internal clock as described by McCleave and Wipfelhauser (1987). This basic module needs some refinements, in relation with problems generated by the model itself or in relation with the new insights. Change in the current direction might synchronize two swimming behaviour: against- or with-current swimming in opposite phase. Photoperiod can also be a synchroniser of the locomotor activity. In addition, glass eels locate in the water column according to brightness, and their negative phototaxis may affect STST. The translation in computer language is realized at an individual level to simulate glass-eel journey through the Gironde estuary. In present virtual experiments, all glass eels will finally reach the tidal limit. However, recent results indicate that some individuals settle in the estuary and never reach freshwater. To take that into account in the model, different mechanisms could be tested in silico approaches, which might generate new questions to investigate in vivo. Among these hypotheses, changes in trophic conditions, the presence of a biological window and the existence of a social facilitation behaviour for synchronisation might be interesting to investigate. The last hypothesis is particularly attractive in light of the high variability observed experimentally in the synchronisation of glass eels swimming activity.

4. The implications of facultative catadromy in the European eel at the drainage basin level

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Our four year UK government funded project "Development and implementation of Biological Reference Points (BRPs) for the Management of the European Eel" has entailed the collection of quantitative eel population data from a series of drainage basins around England and Wales. A GIS platform has been used to examine regional variations in eel population structure and dynamics. Facultative catadromy appears to be part of a flexible continental life history strategy that gives rise to a range of migration, settlement and development patterns in response to variations in glass eel recruitment and habitat availability. The west coast of Britain lies along the main glass-eel recruitment pathway. Here, our data show that, despite a major decline in glass eel numbers over the last two decades, inland migration pressure remains strong and large numbers of elvers penetrate freshwater each summer, giving rise to high density river populations dominated by rapidly maturing males. In contrast, relatively few glass eels now reach the North Sea coast of Britain, probably as a result of early settlement on route. Our data suggest that recruitment is insufficient to saturate coastal and estuarine carrying capacity and that consequently, inland migration pressure is greatly reduced. East coast rivers currently support low population densities of predominantly larger long-lived female eels. The almost complete absence of small eels in river populations implies that eels are not entering freshwater until several years old, if they do so at all. Facultative catadromy and density dependent migration and sex determination allows optimal exploitation of available resources and maximizes the production of large highly fecund females. Understanding the ecological and devel-

opmental plasticity of the European eel has important implications for the management of this currently declining species at both regional and continental levels

5. Impact of river network topology on European eel population dynamics estimated with an individual-based model

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Our work aims to produce tools for stock assessment of silver eels in a watershed, while taking into account the individual variability of biological processes. Individual-based modelling is a suitable approach for representing precisely these dynamics of aquatic population. However its stochasticity make models analysis harder compared to lattice models. Aggregating the hydrographic network would supply a simplification of its representation and a easier interpretation of individual-based model dynamics, furthermore it would reduce computation time. We have developed an individual-based model (IBM) of eels population dynamics in a drainage basin, equivalent to the lattice model, previously developed by (Lambert, 2005, PhD thesis, Univ. Bordeaux). The river network is longitudinally split into homogeneous reaches with same length. All the characteristics of each reach are summed up in a carrying capacity. Recruitment, age-related processes, and movement of individuals are the main mechanisms taken into account Recruitment is modelled with a symmetric beta law, limited by the beginning and ending date of the migratory season. Movement are related to colonization, food research, which depend on departure and arrival reaches saturation. Age-related processes include ageing, sex differentiation, silvering and mortality. Population dynamics is summarized by silver eels production per reach or age structure of silver eels flux. First, we have validated IBM with the lattice model in the same river basin. Then, we have tested with these two models the effect of the topology of the river network. And we have developed some methods to aggregate this network. The consequences of the results on field data interpretation and management advise are prospected.

6. Estimation of downstream migration fluxes of silver eels from various systems: A methodological review and biological implications

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Despite a crucially urgent demand, by managers and stakeholders from local to national and European levels, addressed to scientists, there is still little information about the production of silver eels by continental waters (including habitats from marine littoral areas, lagoons, estuaries and river systems). A review of possible methods is proposed and illustrated from data sets of three different systems : the Loire where a mark recapture experiment is conducted with the colloboration of professional fishermen, the Frémur River a highly impacted short river system, and the Oir a small river in a relatively pristine state. In these systems, intensive monitoring of the eel population has been over a ten years period since 1995. First we provide a comparative description of the methods (direct survey of the runs, indirect estimations from the sedentary fractions of the stocks). Secondly, we present of the main results on the quantification and the characterisation of the silver eel production by these systems. Thirdly, we discuss the possibilities of extrapolation of these results to implement a methodology to estimate silver eel production from data poor ecosystems.

7. Long-distance fish migration: more than a matter of getting from here to there

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Long-distance fish migration is a spectacular example of the ontogenetic niche shift (Werner and Gilliam 1984). Our general perception of these migrations tends toward overly simplistic descriptions, due in part to the impracticality of direct observation, and to the imperfect information derived from tagging studies. I discuss here how relatively new techniques, which exploit the microchemical properties of otoliths (fish earstones), provide detailed information on individual migrating fish. In particular, I show how strontium incorporated into otoliths can serve as a proxy for salinity; how it can be used to study the movements of diadromous fishes; and how this provides a much more complex picture of migration. Other tracers besides strontium permit more detailed analysis of habitat use by diadromous species. These empirical observations place a new demand on ecological theory to explain the rich repertoires of large-scale habitat switching increasingly revealed by natural chemical tracers.

8. Analysis of the level of homing of Allis shad (*Alosa alosa*) in the Garonne - Dordogne basin (south-west France) using otolith chemistry

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The level of homing (i.e. fidelity to the spawning grounds) of the Allis shad (*Alosa alosa*) populations in the Gironde-Garonne-Dordogne system (south-western France) was evaluated using otolith ("ear bones") chemistry. The composition of the otolith core reflecting the water composition during the juvenile stages (i.e. the phase spent in the river before migrating to the sea) constitutes a natural tag and was used to infer the origin of each fish. The inferred natal origin of each fish was then compared to the location where the fish was captured. Otolith cores were analysed in triplicate with Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) at a resolution of 50 microns spots. In total, 108 shad otoliths were analysed (48 from the Dordogne River and 60 from the Garonne River). Linear Discriminant functions established in a previous study to classify the natal origin of young of the year shad (Tomás *et al* 2005) and Artificial Neural Networks were used to classify each fish to one of the two rivers based on the composition of the otolith core. Co, Fe, Sr and Rb were the most influential elements for the discrimination. Based on these results, shads from the Garonne River exhibited a level of homing between 30 and 44% whereas shads from the Dordogne River showed a level of homing ranging between 48 and 68%. These results do not allow to conclude that the phenomenon of homing is different from random in the Gironde-Garonne-Dordogne population.

9. Ecological versatility in eels : tactics of habitat use of the Gironde estuary, a large tidal estuary, implications at the population level

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The environmental history and habitat use of two hundred (200) European eels *Anguilla anguilla*, from the tidal Gironde estuary (130 km long) and the coastal area was investigated by the means of both a microchemistry analysis and an ecology analysis. The analysis was stratified by location (sea, low estuary, upper estuary, river) and by age class of eels. The information of habitat use history provided by the transects of Sr:Ca ratios across the otolith was crossed with retrospective growth history of the fish and with temperature and salinity chronologies of the water from the estuary and the coastal environment. The diversity and repartition of life history types was determined in the estuarine population. The microchemistry of otoliths revealed two types of habitat use, a resident type and a migrant type, the latter being the more abundant. Among migrants, there was a great diversity of life history patterns. The majority exhibited an early catadromous behaviour with a first migration into freshwater followed by a back movement downriver to the mouth of the estuary. For all the migrants the shift of habitat occurred for a narrow range of age between the first and the fourth year of continental age. This phenomenon suggested an implication of density dependent effects linked to the capacity of the watershed to support the eel

population. This hypothesis needs to be tested in other watersheds. The influence of environment events on habitat choices and tactics of habitat use of each age class of eels was tested. Elements of comparison of tactics at the population level between *Anguilla anguilla* and two populations of *Anguilla rostrata* are exposed. Temperate eels appeared versatile in their habitat use tactics, which plasticity is linked with climate and the colonised watershed.

10. Where do all the silver eels come from? New results from the Baltic Sea

Dr Håkan Wickström

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The European eel stock is in severe crisis. Recruitment has been decreasing for more than two decades with the result that both stock and fisheries' yields are now declining and will continue to do so for at least another decade or two. Prior to the formulation and implementation of an international recovery plan, several countries are using re-stocking as a stock enhancement measure. Traditionally the aim was to enhance the fishery but nowadays conservation needs have become increasingly important. To argue for re-stocking as a stock enhancement measure, stocked eels must contribute to the spawning stock. Research has found that some stocked silver eels do not orient normally when leaving their growth areas for the spawning migration and therefore are not able to find their way out of, e.g. the Baltic Sea. To investigate origins of silver eels caught on migration in the outlet from the Baltic Sea (Öresund), we have in autumn 2003 sampled large numbers (750) of silver eels from the commercial fisheries at two sites in the Öresund area. The samples are or will be analysed regarding stage, size, sex, age, fat in muscle and strontium:calcium ratios in their otoliths. In addition, smaller samples (in total 500) were also collected from the commercial fisheries in eight lakes in Sweden. In this preliminary report, we present the different life histories determined by Sr:Ca analyses of otoliths from the Baltic Sea emigrants, and the proportion of stocked eels in different lakes. The following main life histories were found among silver eels leaving the Baltic Sea on their spawning migration:

- * Entire growth in freshwater (i.e. most likely stocked in freshwater)
- * Final growth in freshwater after a natural recruitment through a brackish gradient
- * Entire growth in a brackish environment (stocked or naturally recruited)
- * Final growth in brackish water after being stocked in freshwater
- * Single or recurrent changes between growth in fresh- and brackish water

In most lakes the proportion of stocked eels was considerable. These results are discussed regarding the management of the European eel stock, more specifically how stocked eels and eels from freshwater contribute to the spawning run from the Baltic Sea.

11. Alternative migratory behavior of American eel (*Anguilla rostrata*) in the Saint John River, Gaspé (Quebec)

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Eel species of the genus *Anguilla* are usually considered as catadromous. However, in some European, American and Japanese populations, some eels are exclusively marine whereas others exhibit seasonal migrations between salt and freshwater both at juvenile and adult stages. Such migratory behavior has been observed in the St. John River (Quebec) in 2002 through 2004. We thus hypothesized the existence of conditional life-history strategies whereby alternative migratory patterns are associated with different demographic characteristics. The main objective of field work conducted between May and October 2004 was to determine yellow eel's migratory patterns based on Sr:Ca ratios measured in otoliths and on acoustic-telemetry. According to the Sr:Ca ratios, 16 of 17 eels captured in a lake located within the river system spent their entire life in freshwater after initial river entry. One eel returned to the estuary before returning to freshwater. Of 15 eels caught in the estuary, 9 exhibited periodic migrations between fresh and marine waters after initial river entry and 1 did so but only after a brief period of freshwater residency. Three eels stayed a short time in freshwater before taking up residency in the estuary, 1 eel stayed exclusively in the estuary and 1 spent its entire juvenile life in freshwater. Of 15 eels captured during the spring downstream migration, 11 moved frequently between freshwater and the estuary; 2 did so

following a period of freshwater residency and 4 ceased seasonal migrations to remain in the estuary. Three other eels appeared to be estuarine residents and another one migrated seasonally after a period of residency in freshwater. On a smaller temporal scale, the tracking of 17 eels acoustically tagged during the spring downstream migration showed that 7 eels left the river to feed in the estuary during summer, whereas 6 stayed in the river (4 could not be located). Moreover, some eels tagged in the estuary exhibited regular movements including homing to daytime resting sites. As the existence of several migratory strategies was confirmed, our second objective is to compare eel's biological characteristics according to their migration strategies. We propose that eels exploiting the estuarine environment will grow faster, mature earlier and migrate younger relative to those living in freshwater.

12. Using genetic with stable isotope analyses to investigate hybridization between Atlantic salmon, sea-run and stream resident brown trout in a small stream

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Brown trout *Salmo trutta* and Atlantic salmon *Salmo salar* can interbreed and produce viable hybrid offspring. Literature indicates that maternal species can either be brown trout (North America) or Atlantic salmon (Southern Europe and Ireland), and bidirectional hybridization has also been reported (England, Northern Europe and subantarctic French Territory). In coastal rivers where both species are sympatric, brown trout populations often split into two morphs, stream residents and anadromous (sea-run) migrants. No nuclear DNA marker is available for identification of the two morphs, but Stable Isotope Analysis (SIA) has recently proven useful for determination of maternal anadromous life histories among recently emerged fry. Here we combine genetic analysis and SIA to investigate whether brown trout females of the two morphs may interbreed with Atlantic salmon. In spring 2003, 88 recently emerged fry were collected in La Roche brook (Oir River, Normandy, France), a second order stream that provides spawning grounds for brown trout (freshwater resident and anadromous) and Atlantic salmon. First, microsatellite DNA (6 loci) analysis was carried out to determine the frequency of hybrids in the sample. Two hybrids were found (frequency = 2.3%). Second, the maternal migratory origin (anadromous or freshwater resident) of fry was inferred from SIA (d13C and d15N). One hybrid arose from a freshwater resident female brown trout x Atlantic salmon male cross. The second hybrid has a maternal anadromous origin, but SIA failed in the attempt to identify maternal species (brown trout or Atlantic salmon). Mitochondrial DNA analysis is being performed to clarify this issue. It is suggested that a combination of appropriate tools like SIA and genetic analyses can improve our understanding of complex interactions between anadromous and non-anadromous fish populations.

13. Genetics and ecology of amphidromous gobiids from Mascarene Islands supplying economically important post-larval fisheries

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Recent genetic and ecological studies on amphidromous gobiids supplying goby-fry fisheries on La Réunion Island (*S. lagocephalus* & *C. acutipinnis*) are reviewed. A total of 637 adult specimens of the most abundant species (*S. lagocephalus*) were sampled in 15 rivers from La Réunion (N=398) and Mauritius (N=239) in two years (2000U~ 2002). To describe their population genetic structure, 15 enzymatic systems providing 17 informative loci were used. No clear divergences (Fst tests) can be demonstrated between samples, suggesting a large single cloud of larvae around the two islands. The isolation-by-distance hypothesis has been rejected confirming the great dispersion of larvae (>200Km). A drastic modification of the genetic structure can be observed between the samples collected in 2000 and 2002. Moreover, the results suggest an abundant allo-recruitment: (i) several genetic entities were discriminated by a multidimensional analysis, two in 2000 and three in 2002, different between the two years and characterized by private alleles and (ii) high level of migration rate was measured during this period. In order to evidence the allo-recruitment within a sample of new recruits fry from La Réunion

(99 *S. lagocephalus* and 26 *C. acutipinnis*), the larval life duration has been estimated using the daily increments of otolith. *S. lagocephalus* is a widespread species from all Indopacific area and shows extended larval life (199 ± 33 days), whereas *C. acutipinnis*, endemic to Mascarene Islands shows more limited value (101 ± 14 days). The age distribution and genetic data on these new recruits suggest both allo- and auto-recruitment for *S. lagocephalus* whereas only Mascarene auto-recruitment seems occurring for *C. acutipinnis*. All these results have to be considered for conservation measures in order to prevent the resource decreasing due to overfishing.

14. Change in life histories of migratory salmonids from the River Dee, Wales

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The River Dee supports an important salmon (*Salmo salar*) and a minor migratory trout (*Salmo trutta*) fishery, with currently a three-year mean annual total catch of 1300 and 160 fish respectively. For salmon the change in life history over the last 70 years is described while for sea trout the time series runs from 1967 to present. Salmon have shown a change in run timing with the majority of the fish entering the river between August and October compared with prior to June, historically. This has coincided with a change in the sea age composition, which was dominated by multi-sea winter (MSW) salmon prior to the 1980s after which the proportion of 1 sea winter (1SW) fish increased until now where they dominate the mature population. Growth rate in fresh water remained relatively stable until the mid 1980s and then started to increase such that by the end of their first and second year salmon are 60% and 19% larger than they were historically. This has been reflected in a change in the age composition of smolts where the mean smolt age has declined from 2 years prior to the 1980s to 1.6 years now. There was no observed trend in post-smolt growth. A simple steady state life history model was developed to examine whether changes in mortality and growth could explain the observed change in age at maturity. The model suggests a decline in the instantaneous rate of mortality by 4.1% from 1.537 yr⁻¹ in 1937/8 to 1.600 yr⁻¹ in 1967/9 and a further decline of 11.7% to 1.787 yr⁻¹ in 1997/9 could explain the shift in mean age at maturity from 5.2 to 4.8 to 3.9 years for the three periods examined. For sea trout, similar to salmon, mean smolt age declined from 2.35 years in 1967-69 to 2.06 years between 1997-99. Over the same period marine growth rate increased and the instantaneous rate of mortality decreased. The size at age of sea trout at the end of the 1990s was between 22 and 79 mm greater than during the late 1960s, depending on sea-age category. The instantaneous rate of mortality declined from 1.440 yr⁻¹ to 1.143 yr⁻¹. The changes in mortality and growth rate are likely to explain the change in proportion of sea trout maturing as x.0+ from 80.4% in 1967-69 to 69.7% in 1996-98. The change in mortality and growth are discussed in relation to changes in the fresh water and marine environment.

15. Is the run timing inherited in Atlantic salmon? Previous spawners ascend earlier than they did on their first spawning migration

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The run timing of virgin Atlantic salmon (*Salmo salar* L.) and the previous spawners were analysed in the large subarctic River Teno, northernmost Finland/Norway. Our hypothesis was that the migration timing of previous spawners and virgin first time spawners were similar, based on the assumption that run timing is an inherited trait. In most cases, however, previous spawners were observed to migrate into the River Teno and its tributaries earlier than their virgin counterparts. The difference in run timing was especially clear between one-sea-winter (1SW) virgin salmon and the corresponding group of previous spawners (1S1). Different virgin sea-age classes also showed differences in run timing as multi-sea-winter fish (2-4SW) ascended earlier than 1SW salmon. Females tended to ascend earlier than males. Our results suggest that run timing of salmon is not strictly genetically fixed as previous spawners ascend earlier than they did on their first spawning migration. The run timing of different sea-age groups have major management implications if the populations are heavily exploited using several fishing methods in different periods of the fishing season like in the River Teno.

16. Spawning migration of salmonids (*Salmo* spp.) in two northern Swedish rivers with special reference to post spawning migration of sea trout (*Salmo trutta* L.)

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Wild stocks of Atlantic salmon (*Salmo salar* L.) and sea trout (*Salmo trutta* L.) in the Baltic Sea are threatened by over-fishing, loss of freshwater habitats, and by damming of rivers for hydro-power, etc. A few rivers still support reproduction of anadromous salmonids. We have limited knowledge of their spawning migration, the distribution of spawning sites and utilization of nursery habitats in these northern rivers. Telemetry studies done in the rivers Vindelälven and Piteälven revealed behavioural differences between salmon and sea trout in their spawning migration and chosen spawning areas. Salmon showed a determined and uniform migration pattern whereas sea trout migrated more erratic with several long distance up- and downstream movements during the entire migration. 159 radio-tagged salmon in 1997-1999 and 2002 in Vindelälven and 21 radio-tagged salmon in 2002-2003 in Piteälven exclusively selected their spawning sites in the main stem. The majority of salmon at time for spawning in October were located in minor pool and riffle areas with mixed flow regimes. Spawning took place at depths of c. 1-3 meter. In Piteälven, 74% out of 31 radio-tagged sea trout in 2002-2004, used tributaries for spawning. Here, we located spawning sites in fast flowing water at depths of c. 0.3-1 meter with substrate from fine- to coarse gravel. In Vindelälven, only one individual (2%) out of 56 sea trout used a tributary for spawning. A majority of upstream migrating sea trout were, at time for spawning, positioned in areas in the main stem where previous releases of one-summer old juveniles had been done. 61 % (19 radio-tagged sea trout of 31 tagged in 2003) in Vindelälven survived spawning. Two of these migrated downstream towards the sea immediately after spawning while 90 % (17 individuals) over-wintered in the river. The year after spawning they started their seaward migration as kelts at rising water temperature above +6 °C in May/June after the peak in spring flood occurred. The choice of spawning area, overwintering strategy and migration pattern, both up- and downstream are discussed as important factors to consider when developing a sound management strategy for the anadromous salmonid resource.

17. An in situ experiment to test the importance of body size and condition for downstream migration in anadromous Arctic charr, *Salvelinus alpinus*

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Anadromous (sea-run) and resident (non-migratory) Arctic charr usually coexist within the same lake system. Sea migrants descend in late spring and return to fresh water after 40-50 days at sea. First-time migrants (smolts) have a fairly uniform size but a wide variation in age. Size may therefore be a critical factor for anadromy, and within the youngest smolt year-class, it is the largest fish that migrate. There are also indications that migration to the sea is associated with compensatory growth due to weight loss during the winter. We tested these hypotheses experimentally by releasing a group of juvenile charr of uniform age from the Møkkeland lake system, North-Norway. Eggs from anadromous charr were collected in late autumn, and placed in a hatchery after fertilization. Approximately 15 months after hatching a group of charr yearlings was released into Lake Møkkelandsvatn. The size of released fish fell within the length range of natural smolts in the Møkkeland population. A trap was established in the outlet stream to capture descending fish. The study confirmed our hypothesis that the migrating fraction of the released charr was dominated by the largest and the most slender individuals of that year-class.

18. Lipid energy reserves influence life history decisions of anadromous Atlantic salmon and brown trout

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Energy densities appear to influence salmonid life histories, and this paper gives relationships between life history decisions and energy and lipid densities in parr and smolts of anadromous brown trout and Atlantic salmon. Smolts of Atlantic salmon leaving the river in south Norway have on average between 30 and 40% higher energy level than corresponding brown trout in spring and summer. The difference was chiefly due to 1.8 times higher lipid density in parr and 2.4 times higher lipid density in smolts. The difference was smaller among immature parr in the autumn, with only 1.4 times higher lipid density in salmon than trout, probably because the more energy rich salmon parr had attained maturity at the time. Among mature male parr, the somatic energy density was approximately 11 % higher in trout than salmon. On the other hand, the gonadal energy content was more than twice as high in salmon as in trout. The higher somatic energy allocation in parr of Atlantic salmon probably increase their ability undertake long distance feeding migrations and make large investments in reproduction at the cost of protein growth, compared with parr of brown trout.

19. The endocrine control of the eel (*Anguilla anguilla*) migration

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Individual eels are either marine, estuarine or freshwater residents. The control of these divergent life histories are poorly understood. Here, using ecological, physiological and behavioral approaches, we stress the mediating role of thyroid hormones (THs), triiodothyronine (T3) and thyroxine (T4), in the expression of alternative strategies in the eel. First, to precise the role of THs in the control of both the locomotor activity and the rheotaxis, glass eels, caught during migration in the Isle River (France), were treated by immersion in either a T4 or an antithyroid drug (TU) solution. T4- and TU-treatments significantly increased and decreased, respectively, the glass eels thyroid status. Then, fishes (N = 960) were tested on their swimming behavior in experimental flume tanks equipped with upstream and downstream traps. Compared to control fishes, locomotor activity significantly increased in T4-treated eels, and significantly decreased in TU-treated fishes. This effect was likely due to the regulating action of THs on the metabolic and brain catecholamine pathways. This result shows for the first time in an Elopomorph fish, a primitive Teleost, that THs control the locomotor activity, and indicates that these hormones may play a central role in migration processes. Moreover, T4- and Tutreatments affected the glass eel rheotaxis in different manners, suggesting complex regulation pathways. In a second experiment, to determine whether thyroid status is related to migratory and settling behavior, we sampled glass eels showing different migratory behavior at the tidal limit of the Vilaine River (France), the Arzal dam. Compared to glass eels netted in estuary as they were exhibiting selective tidal stream transport (STST), glass eels from the eel ladder trap had significantly higher whole-body THs levels, indicating an activation of the thyroid gland via the thyreotrop axis. This could be responsible for the behavioural transition (loss of circatidal rhythm and switch to counter-current swimming) at the tidal limit and active colonization of river habitats. Bottom glass eels, caught on the bottom of the estuary during flood tide, had the lowest whole-body THs levels. This suggests that a decreased thyroid status is linked to the loss of the STST and precocious settlement in estuarine and marine habitats. Together, these results indicate that THs are proximate mediators of glass eels dispersal in estuarine and river habitats. THs have been shown to be linked to migrations and (or) to promote locomotor activity in salmonids, Gadidae, and cyprinids. The present results, obtained in a representative of an ancient Teleost group, suggest that THs may represent phylogenetically conserved proximate mediators of Teleost migrations and diadromy.

20. Calcitonin-gene related peptide : a new hormone involved in ionoregulation in teleost

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In mammals, alternative splicing of the calcitonin gene generates two distinct peptides: calcitonin (CT), which is synthesized in the thyroid C cells and involved in the regulation of calcium metabolism, and calcitonin gene-related peptide (CGRP), which is a neuromediator synthesized in the brain and the peripheral nerves. CGRP is well represented and molecularly conserved during evolution but its function has not been yet characterized in many species. We have identified this peptide in the eel, *Anguilla anguilla*, an ancient teleost. We used radioimmunoassay and radioreceptorassay to detect the presence of molecules immunologically and biologically related to CGRP in different tissues. CGRP-like molecules have been found mainly in brain, heart and spleen. Partial purification, by gel exclusion chromatography and HPLC, followed by SDS-PAGE, showed that these CGRP-like molecules present a molecular weight of around 3300 Da, similar to that of human CGRP (3750 Da). In plasma, the high circulating levels of CGRP-like molecules measured in the eel, suggest that this peptide may have an endocrine role in teleosts. The role of CGRP was then investigated by looking for its specific target organs. Binding studies demonstrated that CGRP binds specifically to brain, heart and gill membranes. Thus, gill presented one of the highest CGRP binding while the peptide itself was not detected in this organ. Gill could therefore represent one of the targets of the endocrine role of CGRP. We then investigated the possible role of CGRP in osmoregulation by transferring eels from freshwater to seawater. In fact, during the migration from freshwater to seawater, eels are subjected to a high osmotic stress. Change in plasma osmolality was observed with a significant increase from the value of the controls, since 2 hours of transfer to the long-term adaptation. The concentrations of CGRP-like molecules in plasma presented a significant increase during all the experiment, since 2 hours of transfer. The specific binding sites of CGRP in gill membranes were characterized by a Scatchard analysis and studied during the seawater transfer. The number of binding sites showed a significant and transient increase, after 2 hours in seawater, with no significant variation in the affinity constant. This increase, in both CGRP plasma levels and CGRP receptor number, indicates an upregulation by CGRP of its specific receptors and has been described for other peptides hormones. We also demonstrated that CGRP seem to be involved in another teleost, the trout, *Oncorhynchus mychiss*, during transfer from freshwater to seawater and from seawater to freshwater. Ionoregulation homeostasis is a major challenge in fish and specially in diadromous species. Our studies indicate that CGRP represents one new important hormone involved in the complex and multi-hormonal ionoregulation mechanisms in teleosts.

This work was supported by a grant from the European Community (EELREP No. Q5RS-2001-01836).

21. Silvering process and pressure resistance in the eel: regulation aspect

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During their migration (about 6000 km) eels are submitted to hydrostatic pressure (HP). Before this migration, they metamorphose (silvering process) from yellow (sexually immature) to silver stage. In this work, effects of HP and/or silvering have been studied on aerobic metabolism and more precisely on reactive oxygen species (ROS) production. In terms of pressure resistance, previous studies have shown that silvering process appeared to mimic pressure acclimatization. The physiological state of yellow pressure acclimatized eels can be compared to those of silver eels at atmospheric pressure. Really, HP acclimatization of yellow eels improves the oxidative phosphorylation together with a supposed concomitant decrease in electron leak and ROS production. In order to verify this hypothesis, hydroxyl radical (OH_2T) production, the end by-product and the most reactive of ROS, and oxygen consumption were measured in vitro on red muscle fibres. Experiments were performed on yellow and silver eel acclimatized to HP (21 days to 101 ATA) and on control groups (21 days to 1 ATA). In control groups, results show a significant higher oxygen consumption for yellow eels (about +30%, $P < 0.005$) than silver eels; this is accompanied by a significant higher OH_2T production (about + 77%, $P < 0.05$). The HP acclimatization does not modify these parameters in silver eels but erases the difference between yellow and silver eels. These results verify the hypothesis that pressure modifies ROS production without modifying the regulation of electron flux through the respiratory chain. They also confirm the previous observation that silvering process is similar to yellow pressure acclimatization. To complete this study and to have a dynamic approach of eel ROS

metabolism, the detection of antioxidant defences (superoxyde dismutase, catalase) is in progress in our laboratory.

This study was supported by the EU project EELREP Q5RS-2001-01836

22. Mimicking environmental conditions of European eel oceanic migration: Effects of exposure to high hydrostatic pressure on the brain-pituitary-gonad axis

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Eels exhibit a striking life cycle of which the silver stage represents the last phase available under natural conditions. Indeed, silver eels are sexually immature and remain blocked at a prepubertal stage as long as their reproductive migration does not occur. Therefore, we can hypothesize that one or more external factor encountered during the oceanic migration would resume their gonadal development. Available data suggest that eels migrate at depth and consequently they are submitted to high hydrostatic pressure (HP). Thus, we have investigated the possible pressure effects on the reproductive function of European eel, *Anguilla anguilla*. Female and male silver eels were placed in a hyperbaric chamber with a HP water circulation system (UHPM, Brest). We investigated the effects of 3 weeks exposure to HP of 101 ATA (atmosphere absolute; 1ATA = 0,1 Mpa) on the brain-pituitary-gonad axis. Because dopamine is known inhibit gonadal development in eel, brain dopaminergic activity was estimated through quantification by quantitative real-time RT-PCR of expression tyrosine hydroxylase (TH), the rate- limiting enzyme of catecholamine synthesis. In addition, parameters of gonad activity were measured. In males, plasma steroids (T, 11-kT) were assayed (ELISA). In females, plasma levels of vitellogenin and steroids (T, 11-kT, E2) were assayed (ELISA), and gonado-somatic index (GSI) and oocyte diameter were measured (histological image analysis). In both sex, we found a decrease in TH mRNA levels in specific brain regions, including the nucleus preopticus antero-ventralis, where the dopaminergic neurons responsible for the inhibition of reproduction in teleosts are located. Inversely, increases in steroids and vitellogenin levels together with GSI and oocyte diameter were observed. The effects of HP were limited and significant only for oocyte diameter. This may result from the short duration of the experiment as compared to the presumed length of migration (>5 months). This first study suggests that HP, a deep-sea factor, may participate in the activation of the eel reproductive function via a decrease in the brain dopaminergic activity. In order to confirm the role of this external factor in the stimulation of eel reproduction, male silver eels are currently exposed to HP for 3 months. This work was supported by a grant from the European Community (EELREP No.Q5RS-2001-01836)

23. Swimming performance and behaviour of upriver-migrating adult sea lamprey (*Petromyzon marinus* L.) assessed in laboratory by electromyogram telemetry

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A primary goal in fish behaviour studies, particularly those with respect to migrants, is to obtain direct measures of the nature and locomotors activity of their journey in the wild. The use of telemetry, namely the electromyogram (EMG) technique, to study the anadromous spawning migration of the sea lamprey (*Petromyzon marinus* L.), have been proved from early studies, to be an useful method to improve the knowledge on the ecology and behaviour of this species, and as a mean to support the drawing of management and conservation proposals. The main objective of this laboratory study was to methodologically gauge the application of electromyogram (EMG) telemetry, namely the new coded electromyogram (CEMG) transmitters from Lotek Wireless Inc., to studies involving the monitoring of sea lamprey anadromous migration. The transmitters were surgically implanted in the peritoneal cavity of 9 animals, and the electrodes fixed in the red axial musculature. This methodology allows gathering information concerning the activity patterns, behaviour and swimming capacity of the sea lamprey, when subjected to distinct current speeds. The poor swimming capacity of the anguilliform type of locomotion was once more documented by the application of the Critical Swimming Speed method (CSS) using untagged lampreys. The average CSS observed was c.1.03 m s⁻¹ (i.e. 1.14 BL s⁻¹), ranging between 0.82 m s⁻¹ (1.01 BL s⁻¹) and 1.19 m s⁻¹ (1.34 BL s⁻¹), and the reotaxic response was more satisfactory with current speeds between 0.4 m s⁻¹ and 0.8 m s⁻¹. In order to guarantee the reliability of the data collected in the field, a calibration of the EMG records with swimming speed must be done. This procedure is very important to ensure a cor-

rect interpretation of the locomotion and activity patterns of the animals in their natural environment. Despite the high correlation between EMG values and swimming speed, due to an evident variability between individuals it was impossible to define a general pattern that could lead to the application of the laboratory calibration to non-calibrated field data. Consequently, the solution is to calibrate the EMG values of each animal using laboratory procedures, before being released in the field. The observed variability might have been caused by individual differences in behaviour and/or physiology. Aspects like time of migration, sex and maturation stage may also influence the detected variability. The EMG technique and the CEMG transmitters, were recognized to be a useful and reliable tool as indicators of muscular activity, and therefore can be used to study in situ the sea lamprey migratory behaviour.

24. Early Sexual Maturation in Atlantic Salmon Male Parr: Role of Growth Regulating Factors in the Onset of Maturation

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Atlantic salmon show large variations in life history patterns. Male salmon may either mature as small parr in freshwater or later at large size after having spent one to several years in the sea. Early sexual maturation in male parr is common in wild and hatchery reared populations and in hatcheries producing Baltic salmon smolts for compensatory release about 50% of the males may mature at one-year of age. Both genetic and environmental factors influence the age of sexual maturity and many data indicate a strong relationship between body growth and age of maturation. In fish, as in other vertebrates, sexual maturation is characterized by an activation of the brain – pituitary - gonad axis, but the underlying regulatory mechanisms of this activation are still poorly understood. To understand the relationship between regulation of body growth and the onset of maturation, we studied the expression of gonadotropin subunits (FSHb and LHb) and growth promoting genes (growth hormone (GH) and insulin-like growth factor I (IGF I)) during spermatogenesis in early maturing Atlantic salmon. Gonadotropin transcript levels varied during the sexual development of the fish. FSHb abundance increased during the period of spermatogenesis in August, while LHb levels increased in mid September at the beginning of spermiation. GH mRNA expression increased in spring during the period of enhanced growth with no differences observed between immature and maturing fish. IGFI transcript levels increased during maturation and were significant different in September compared to immature males. Treatment of pituitary cells with IGFI had stimulatory effect on LHb expression indicating a possible link between signals concerning body growth and the onset of sexual maturation

25. Dopaminergic inhibition of eel reproduction: ontogeny and regulation by sexual steroid hormones

Dr Finn-Arne Weltzien, Sylvie Dufour , Bernadette Vidal, Catherine Pasqualini, Sylvie Baloché, Nadine Le Belle & Philippe Vernier

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In many adult teleosts, dopamine (DA) plays an inhibitory role on the control of LH and on ovulation/spermiation. In the European eel, recent results from our lab show that DA can act also at earlier stages, as a strong inhibitor of pubertal development in silver eels until the reproductive oceanic migration takes place. However, the ontogeny and regulatory mechanisms of this DAergic inhibition have not been investigated. In the present work we have studied the ontogeny of brain expression of tyrosine hydroxylase (TH), the rate-limiting enzyme in the biosynthesis of DA and often used a measure of DA activity, in female eels from the yellow to silver stage and further through artificial maturation. The expression of TH, measured by quantitative real-time RT-PCR and in situ hybridization, was highest in the olfactory bulb, followed by the telencephalon including preoptic area, and the di-/mesencephalic areas excluding the optic lobes. TH expression in the various brain regions varied with development. Chronic in vivo treatments with sexual steroids revealed that testosterone and estradiol differentially affected the expression of TH in various parts of the brain in female silver eels. These results provide a new basis for understanding the ontogeny and regulation of central DA inhibition of pubertal development in the European eel. Improved understanding of pubertal development is especially important in the

case of the eel, both in terms of species preservation and for development of aquaculture, because of its special life cycle which is particularly vulnerable to environmental changes.

This study was supported by a Marie Curie Individual fellowship (MCFI-2002-01609) to FAW, and by an European project (Q5RS-2001-01836 -EELREP) to SD.

Presentations:

Session VI “Human activities and Diadromous fish”

1. Essai sur l’histoire de l’esturgeon *Acipenser sturio*, ou comment utiliser les enseignements d’un déclin dramatique

Dr Patrick Williot & Gérard Castelnaud

Cemagref, Cestas, FRANCE

L’esturgeon ouest européen *Acipenser sturio* est l’esturgeon ayant eu l’aire de distribution la plus variée et l’une des plus étendue. Il a été présent depuis la Mer Noire (Rioni et Danube), la Méditerranée centrale (Grèce), l’Adriatique (Pô), la Méditerranée occidentale (Le Rhône en France et l’Ebre en Espagne), la péninsule Ibérique (Espagne (Guadalquivir)) et le Portugal, la France atlantique (Grands fleuves français en particulier le bassin Gironde - Garonne - Dordogne), la Manche (Seine et côtes anglaises), la Mer du nord (Hollande, Grande Bretagne, Allemagne) et la Mer Baltique (Pologne, Suède, et Russie). Il n’est plus présent que dans le bassin Gironde - Garonne - Dordogne en France par une petite population dont tous les signes récents sont très alarmants en dépit d’une protection officielle en France depuis 1982. Les conditions dans lesquelles les essais de conservation ex situ sont menées sont telles que les plus grandes inquiétudes sont de mises quant à la survie de l’espèce. Cette proposition a pour but de : i) Faire le point des captures signalées autrefois dans divers pays en particulier ceux à la limite de l’aire de répartition (Suède, UK, Irlande notamment). Cela pourrait permettre de préciser le déclin dans le temps dans diverses zones. ii) Compléter la liste des causes de ce déclin. Les aspects organisationnels seront pris en compte (administration des pêches, organisations professionnelles, modalités de gestion des espèces exploitées etc...). iii) Tenter de hiérarchiser les causes et dans la mesure du possible. iv) Analyser les raisons de l’inefficacité des mesures prises dans le passé lorsque celles-ci ont existé. Ceci devrait être mené aux plans réglementaires et scientifiques. v) Faire le point sur les conditions et l’avancement des travaux menés dans le cadre de la conservation ex situ. vi) Etablir une synthèse de ce qui aurait dû être fait à diverses périodes pour éviter cette évolution dramatique pour cette espèce d’esturgeon. vii) Dresser un canevas de propositions qui pourrait servir de guide plus général. On essaiera à ce niveau de distinguer ce qui ressortit de la recherche de ce qui dépend de l’organisation des pêches.

2. Restoration of American Shad to the Susquehanna River, USA

Mr Richard St. Pierre

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The anadromous American shad (*Alosa sapidissima*) is the largest member of the herring family in North America. It reproduces in freshwater reaches of large rivers from Canada to Florida and spends most of its life at sea making extensive coastal migrations. The Susquehanna River, historically the largest and most important of the shad rivers, originates in southcentral New York and flows 700 km southward across Pennsylvania before emptying into the Chesapeake Bay in Maryland. Throughout the 19th Century, shad in the Susquehanna were impacted by adverse water quality, overfishing and development of industrial and canal dams. Construction of four large hydroelectric dams in the lower 88 km of river in 1904-1931 further restricted spawning migrations to only the lower 16 km of river. The U. S. Fish and Wildlife Service, fishery agencies from the three basin states, and the owners of the four hydroprojects on the Susquehanna joined to form a partnership aimed at restoring this lost resource to the river. Members of the Susquehanna River Anadromous Fish Restoration Committee embarked on an ambitious stock rebuilding effort which has included culture and stocking of over 200 million larval and fingerling shad, trap and transfer of over 250,000 adult spawners to waters above all dams, and construction of some of the largest fish passage projects in the eastern U.S. Susquehanna shad restoration partners have addressed many biological and technical challenges over the years. These have included development of large-scale intensive culture and mass marking techniques for larval shad, improved handling and transport methods

for adult shad, and construction of state-of-the-art fish elevator systems. Other innovations included use of balloon tags for measuring survival of juvenile shad passing through turbines and broad application of radiotelemetry to study adult and juvenile fish movements related to dams. The shad population returning to the lowermost dam has grown from a few hundred fish each year during 1972-1984, to several tens of thousands in the early 1990s, to well over 100,000 each year during 2000-2004. Shad restoration in the Susquehanna is far from complete and huge sport fishing benefits are yet to be realized, but the dramatic progress achieved to date portends well for the future.

3. The Allis shad (*Alosa alosa*) population of the River Rhine: Background, status and perspectives for a restoration programme

Dr Peter Beeck, Philippe Jatteau, Barbara Klee & Detlev Ingendahl

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Until the end of the 19th century the spawning runs of Allis shad into the River Rhine and its major tributaries supported the commercial fisheries in the Netherlands and in Germany substantially. Between 1880 and 1890 the fishermen in the Netherlands caught annually between 150.000 - 270.000 Allis shads. After 1890 there was a strong decline in the catches and already 20 years later the population collapsed. Today, only single Allis shad are caught in the River Rhine. The major reasons for the breakdown of the population were overfishing, pollution and the construction of migration barriers. After a major fish kill in the 1969 the water quality of the Rhine improved steadily and today more than 40 fish species are living in the river again. In 1988 started the restoration programme of the Atlantic salmon (*Salmo salar*) and since then more than 2500 returners have been registered in the River and its tributaries. Thus, the restoration of other long distance migratory fish species, like Allis shad, comes into focus. Two years ago a collaboration between the French CEMAGREF, the State Agency of Ecology in North Rhine Westphalia and the University of Cologne, Germany was initiated to prepare the scientific background for a restoration programme of Allis shad. The project was funded by the HIT Environment Foundation. A feasibility study according to the IUCN guidelines for the re-introduction of animals was conducted. This included genetic analyses of recent allis shad catches from the Rhine with other European populations. The results of the genetic analyses using mtDNA and AFLP analysis indicate that the recent Rhine catches are either strayers from the Garonne population or, if they represent remnants of the original autochthonous population, extremely similar to the Garonne population. In 2004 reproduction and rearing experiments in France were combined with a first transport of allis shad eggs and larvae from Garonne spawners to Germany. The eggs and larvae survived the transport and could be reared in different facilities. The promising results will be the basis for an application of EU funding for a cross-national restoration programme.

4. Shad life histories and mercury contamination

Ms Aude Lochet, Régine Maury-Brachet, Claire Poirier & Eric Rochard

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Allis shad *Alosa alosa* and Twaite shad *Alosa fallax* are two close anadromous Clupeids sympatric in the Gironde watershed. Recent evidence on fish mercury contamination in the Gironde estuary reveals that Twaite shad is a highly mercury-contaminated species. Thus, an evaluation of the contamination of Allis shad, that support a large fishery, is needed as well as an examination of the variability of this contamination in both populations. Ecological aspects, life history strategies of both species (age at maturity, diet) and tactics of individuals (duration of their estuarine stay), are used to understand mercury contamination. Adult fish were sampled during the spawning migration 2003 in the Gironde system. Total mercury and methylmercury concentration have been assessed in 40 fishes (of both species, sexes). The extent of contamination has been investigated in liver, gills, dorsal skeleton muscle and kidney. Migratory tactics of individuals have been identified by the temporal pattern of Sr/Ca ratios along otolith transect, from birth to the date of capture. A Wavelength Dispersive Spectroscopic (WDS) microprobe has been used for analysis. For both males and females, mercury concentration is significantly higher in Twaite shad than in Allis shad. In Allis shad, it is significantly higher in males than in females whereas in Twaite shad it is slightly higher for females than for males. Among the life trait differences, diet could explain the observed level of contamination. Allis shad is mainly planktivorous whereas Twaite shad is mainly piscivorous. As mercury tends to accumulate in trophic network, contamination is to be different. Envi-

ronmental contamination cannot be excluded. Mercury contamination in estuary is higher than in rivers or in the ocean and the estuary residence time of *A. fallax* is longer than for *A. alosa*. As they vary in the same sense these two putative ways of mercury contamination in the Gironde system cannot be split.

5. Chutes and ladders and other games we play with rivers

Dr Henriette (Yetta) Jager

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Our understanding of how river fragmentation by dams influences fish populations lags far behind our willingness to conduct large-scale field experiments. Even for facultatively anadromous species, such as the white sturgeon (*Acipenser transmontanus*), fragmentation and asymmetric migration associated with dams can have negative consequences. An individual-based model for white sturgeon was used to simulate the effects of river fragmentation by dams and the effects of reconnection options. I simulated translocation and upstream passage, both alone and combined with mitigation of entrainment mortality via screening or downstream passage. Simulations of fragmentation showed that upstream populations were at the greatest risk, and that placing dams too close together can create many sink populations out of what was previously a demographic source. This suggests that upstream reconnection options should be beneficial. Simulation of reconnection options suggest that upstream reconnection does not necessarily benefit the metapopulation because of negative effects on the donor population and increased numbers exposed to turbine mortality during downstream migration. Simulated metapopulations were more likely to benefit when downstream passage or screening was also provided, and when fish were moved far upstream to a long river segment. Translocation to a far-upstream long segment with narrow screening at the dam below allowed the recipient to serve as a source population for shorter downstream segments. Likewise, upstream translocations to a long segment benefited the metapopulation if downstream passage was provided at dams between the donor and recipient segments.

6. Passage problems for upstream & downstream migrating anadromous salmonids (*Salmo salar* & *S. trutta*) in two flow controlled northern Swedish rivers

Dr Hans Lundqvist, Peter Rivinoja, Kjell Leonardsson, Johan Östergren, Jaan Kiviloog, Lars Bergdahl, Skip McKinnell, Lars Brydsten

SLU (Swedish Univ of Agricultural Sciences), Umeå, SWEDEN

In-river passage problems for anadromous salmon and trout in flow-regulated rivers that have remaining spawning grounds exist in most European countries. These problems affect the long-term survival of salmonids since their upstream migration are impaired and/or delayed, while downstream migrants show an increased mortality after turbine passages. Our objectives are to identify fish passage problems for migrating salmon at flow-regulated rivers. The overall aim is to minimize the impact that hydroelectric facilities have on migratory fish so future fish resources should not be harmed. We examined salmon and sea trout migrations in two northern rivers, i.e., the Piteälven and Umeälven, with an annual mean flow of c.150 m³/s and c.430 m³/s, respectively. We followed the upstream migration of salmon from the estuary to the fishladder in a flow controlled bypass area, we evaluated the downstream smolt migration of salmon and trout approaching and passing a hydroelectric complex, and we build up numerical flow models to study successful and unsuccessful up- and downstream passages. We summarize results from 1995 to 2004 of tracking radio-tagged upstream migrating salmon at Umeälven (N = 447). Control fish were tagged using internal PIT (passive integrated transponder) tags and external Carlin tags (N = 1759). The proportion of salmon passing from the coastal tagging site to the fish-ladder 32 km upstream varied between 18- 49 % over the years demonstrating an average loss of 70 % potential spawners. Turbine outlet water attracted salmon away from the upstream migration route. Releases upstream the power-station of 150 two-year old hatchery-reared Atlantic salmon (mean length: 20.4 cm) and 56 brown trout (23.8 cm) smolts, internally radio-tagged, were done in spring 2002, 2003 and 2004. We found migrating smolts of both species moving at an average speed of c. 0.4 m/s (c. 2 bodylengths/sec) in the main current in the river before entering the turbine intakes at the power-stations. A mortality rate of c. 18 % for fish passing the turbines at Piteälven was calculated. We discuss long-term solutions to detected migration problems for salmon and trout so that a sustainable population could be managed in the future. Modelling of the population dynamics of the

salmon stock, when they hopefully can bypass the power station more successfully in the future, shows a potential increase in number of future spawners in a very positive way, ie. an important conservation goal.

7. Factors influencing weir passages during the upstream migration of adult Atlantic salmon (*Salmo salar* L.) in two French rivers

Mr Olivier Croze, Frédérique Bau, Thomas Breinig, Hugues Jourdan & Angéline Sénécal
CEMAGREF/GHAAPPE, TOULOUSE, FRANCE

Several radio-tracking campaigns were undertaken in a small river in Brittany (the Aulne river) and in a large river in the southwest of France (the Garonne river). They aimed to study the anadromous migration of Atlantic salmon under different environmental conditions and particularly the passability of the obstacles encountered by fish during their upstream migration. The types of obstacles were different for each river: the Aulne has a series of moderately high installations marking navigation weirs, while the Garonne is blocked by larger installations. These obstacles are all fitted with a fish pass. The environmental conditions for passing the obstacles were recorded for the two rivers, including passing times, flow rates and water temperatures at the time of passing. Passability of the obstacles varied according to the years, for both rivers. It would appear to depend heavily on flow conditions at the time fish reached the obstacles. On the Aulne, high flow rates favoured higher percentages of fish passing a weir and also higher number of obstacles negotiated by each salmon, because fish can directly leap over the obstacles. Conversely, in the Garonne, the lowest flow rates make it easier for fish to find fish passes that are located close to hydroelectric plants. The results also revealed that learning experience was a significant factor for fish migrating in the Aulne. Salmon spent less time blocked at the weirs fitted with efficient fish passes if they had already encountered the same type of installation during their upstream migration. All of the results pointed out the importance of conducting studies over several years and under different environmental conditions, in particular hydrological conditions, in order to ensure a satisfactory evaluation of the passability of an obstacle or migration route. They may also be a useful source of information for designers to help them choose a particular fish pass type according to the range of flow rates during which they may be operational.

8. Survival of juvenile salmonids through turbines at Columbia River dams

Mr John Ferguson

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Evaluations of fish survival associated with two turbine operations at McNary Dam on the Columbia River found no differences in survival through Kaplan turbines between two operations using state-of-the-art telemetry techniques. Estimated relative survival to a detection array 15 km downstream was 0.871 and 0.856 for the 317 and 464 m³/s operations, respectively (P=0.435); survival to an array 46 km downstream was 0.858 and 0.814 for the same operations (P=0.403). The highest point estimates of survival occurred under the lower discharge, suggesting that at this project operating turbines within 1% of peak unit efficiency offers a useful fish protection guideline. The use of this guideline at Columbia River dams to improve salmonid survival through turbines will be discussed. A concurrent evaluation using balloon tags estimated direct survivals of 0.930 and 0.946 for the 317 and 464 m³/s operations, respectively. Differences between the two estimates provide evidence of delayed mortality below the dam. Based on a review of the literature, this delayed passage mortality was likely caused by losses to tailrace predators caused by sublethal impacts to fish sensory systems. I will present how delayed mortality can be a significant component of overall mortality that should be incorporated into survival estimates, and future research should focus on these sublethal effects to improve turbine operations and designs for fish passage.

9. Field experiments on the effects of hydropeaking on Atlantic salmon (*Salmo salar*) in the Dordogne basin (France)

Dr Matthieu Chanseau, Jean-marc Lascaux & Michel Larinier

MIGADO, Le Passage, FRANCE

During the last century, numerous hydroelectric plants were built in the middle and upper parts of the Dordogne basin (in southwest France). The use of hydropeaking causes large and sudden fluctuations in water flow in many rivers which can have a serious impact on Atlantic salmon (*Salmo salar*), disturbing their spawning activity and reducing the juvenile survival rate. Several experiments were thus conducted in the area to quantify the effects of hydropeaking on Atlantic salmon. The first experiments were undertaken on the River Maronne, a tributary of the Dordogne, which was selected because of its extensive spawning activity (539 redds were counted from 2001 to 2003), its small size, its considerable variation in flow and knowledge of its hydraulic functioning (based on a hydraulic model). The effects of hydropeaking on redd stranding were precisely determined: without mitigations, a mean of 25% of redds were stranded each year. Mitigations (i.e. increasing minimal flow value and time of delivery) have led to 95% of total redds being saved on the river. Alevin stranding and trapping were clearly identified and the first quantitative estimations were made. Experiments were also conducted on the Dordogne. An hydraulic model and visual observations of spawning activity were used to evaluate redd stranding. Using electro-fishing, it appeared that the abundance of fish observed in different reaches of the river was not necessarily related to the spawning activity one year earlier. The hydraulic characteristics of the reaches and the distance from the power plant had a significant influence on the abundance observed. Marking operations have made it possible to relate fish movements to flow variations, in particular for a large drift of wild juveniles over several kilometres, which may have serious effects on recruitment. The impact of rapid flow variations on the other diadromous fish species are not well documented for the Dordogne basin. Concerning the shad *Alosa alosa*, hydropeaking may not have a real effect on the population, due to its biological characteristics and the spawning period. The lamprey *Petromyzon marinus* is probably more sensitive to flow variations, particularly at the larval stage. The first experiments were conducted on the River Maronne, a tributary of the River Dordogne, which was selected because of its extensive spawning activity (539 redds counted from 2001 to 2003), its small size, its considerable flow variations and the knowledge of its hydraulic functioning (hydraulic model). The effects of hydropeaking and of mitigation measures on redd stranding were precisely determined: 95% of redds are not at risk from stranding and mitigation has led to 20% of them being saved. Alevin stranding and trapping were clearly identified and the first quantitative estimations have been made. Experiments were also conducted on the River Dordogne. Visual observations of spawning activity and a hydraulic model were used to evaluate redd stranding. Using electro-fishing, it appeared that the abundance of fish observed in different reaches of the river relied more on the hydraulic characteristics and/or on the distance from the reach to the power plant, rather than on the spawning activity in the same reach one year earlier, thus revealing the considerable effects of sudden variations in flow. Marking operations have made it possible to relate fish movements to flow variations, in particular for a large drift of wild juveniles over several kilometres, which may have serious effects on recruitment. The impact of rapid flow variations on the other diadromous fish species are not well documented for the Dordogne basin. Concerning the shad *Alosa alosa*, hydropeaking may not have a real effect on the population, due to its biological characteristics and the spawning period. The lamprey *Petromyzon marinus* is probably more sensitive to flow variations, particularly at the larvae stage.

10. The influence of migration barriers on the upstream migration of diadromous fish in the river Scheldt (Belgium)

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The River Scheldt (Belgium) has one of the few estuaries in Europe with an extensive salt-, brackish- and freshwater tidal system. We studied the impact of two migration barriers on the status of the diadromous fish population in the River Scheldt. The tidal weir (km 160) constituted the first barrier, the second barrier was at a short distance upstream (km 170). At both barriers, we analysed the upstream migration of diadromous fish species from January until December 2002 through fyke net sampling. In the brackish part of the estuary we recorded 6 anadromous and 2 catadromous species. Further upstream the number of diadromous species declined, although at least 4 diadromous species reached the most inner part of the estuary. This rain-fed river showed considerable variation in discharge during 2002. Discharge was high from November through March, causing free flowing

conditions at the tidal weir that offered opportunities for diadromous species to migrate upstream. By contrast, during summer free flowing conditions at the tidal weir were absent and upstream migration was disabled. Upstream migration over the second barrier (km 170) is almost completely blocked. Fish passage of the upstream migrating diadromous population was estimated to be lower than 5%. We discuss some rehabilitation schemes (building, evaluation and costs of fish bypasses) to restore populations of diadromous fish species.

11. The evolution and selective advantages of facultative catadromy in anguillid eels

Dr Brian Knights, Tony Bark & Beth Williams

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Anguillids belong to the monophyletic Elopomorpha characterised by oceanic breeding and a unique planktonic leptocephalus larva adapted to oligotrophic sub/tropical oceanic waters. Larvae migrate towards more productive coastal waters utilising gyre currents. During evolution, it is argued, euryhalinity and general physiological robustness allowed opportunistic penetration of estuarine, brackish and freshwaters by the yellow eel growth stage. Reliance on major gyre currents has limited the number of northern hemisphere species but has allowed them to colonise a wide latitudinal range. These adaptations not only greatly extend habitat and feeding opportunities but also allow anguillids to avoid and to rapidly (re)colonise ephemeral and disturbed habitats. The selective advantages of (facultative) catadromy are further discussed in relation to periodic life-history strategies, resource partitioning, survival specialisations of the leptocephalus and the high plasticity of habitat and prey choice of yellow eels. Diurnal cryptic behaviours conserve energy and help minimise inter- and intraspecific interactions and competition. Density-dependent intraspecific interactions (plus cannibalism) appear important in determining population distributions and size-frequency structures. Life stage adaptations and compensatory size-dependent fecundity to meet the energetic and mortality costs of migrations are discussed. Sex determination appears to be density-dependent on local and geographical scales, promoting resource-partitioning and avoidance of intraspecific competition. This also compensates for potentially large variations in recruitment, e.g. if recruitment declines, falling densities lead to relatively more females and hence overall corrective increases in fecundity. Adaptations are discussed in relation to natural versus anthropogenic influences and to stock management implications.

12. Biology and Management of the catadromous European Eel *Anguilla anguilla* L. in the Lower River Shannon, Ireland

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The European eel is a fish of significant ecological and commercial importance. Because of its extensive migrations and longevity, it is a unique indicator of the health, integrity and connectivity of our oceans, estuaries and freshwaters. However, in recent decades this fish has undergone a dramatic decline throughout its range. Although the cause of this remains to be established, various factors such as disease; pollution; habitat degradation; obstacles to riverine migration; and variation in oceanographic currents, have been implicated. The River Shannon (catchment area 11,700 Km²; mean annual discharge 176m³sec⁻¹) is the largest river in the British Isles. Hydro-electrification of the river in its lower reaches during the 1920's significantly reduced natural recruitment of eel to the catchment, and this has been mitigated since 1959 with a trapping and overland transport programme. Although this endeavor was initially effective, the numbers of eels trapped has progressively declined from the early 1980's onwards. In the current study, available historical information on this trapping programme is reviewed and an intensive study undertaken during the period to 1995 to 1999 is reported. This study involved an assessment of approximately 18.6 million immigrating juvenile eels on the lower Shannon using estuarine netting, riverine trapping and electrical fishing. The results show that despite the global downturn in the abundance of this species, significant stocks of juvenile eel continue to enter the Shannon estuary. However, riverine recruitment continues to be poor due to a range of environmental factors. The influences on juvenile eel recruitment to the river are examined and the role of the eel as a sentinel species of environmental health in brackish and freshwater ecosystems is discussed.

13. Management of Silver Eel: Human Impact on Downstream Migrating Eel in the River Meuse

Mr Maarten Bruijs, Ulrich Schwevers & Beate Adam

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Human impact on downstream migrating silver eel in European inland waters mainly consists of withdrawal by commercial fisheries and extra mortality of eel due to passing turbines of hydropower facilities. These activities are widespread in European rivers and might have detrimental effects on the population level of the European eel. The project presented here was performed in the period 2001-2002 with the aim to investigate the downstream migration of silver eel in the Dutch section of the river Meuse and to quantify the mortalities caused by commercial eel fisheries and hydropower stations, as well as to evaluate the applicability of the Migromat[™], an early warning system predicting downstream migration events of silver eel. These goals have been achieved by monitoring downstream migration of silver eel (telemetry), eel catches by commercial fisheries and assessment of eel mortality at a hydropower station. The research programme developed to achieve the goals has shown to be successful. Both hydropower and commercial fisheries substantially reduce the number of silver eel that reach the sea. Therefore, management measures taken in each of these impacts will directly contribute to an increased size of the spawning population. The migration events in the river found by the different monitoring experiments correspond with the warnings provided by the Migromat[™]. As the system accurately predicts the downstream migration events of silver eels, it enables eel-friendly hydropower turbine management. Hence a high percentage of downstream migrating eels can be saved. The combined results provide a scientific basis for further development of technical measures and management actions in order to reach the 'silver eel escapement targets' set out in the management plan under development by the European Commission.

14. Predicting spawner escapement of the European eel over time after management actions

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The European eel (*Anguilla anguilla* (L.)) is in a severe crisis with rapidly decreasing glass eel recruitment since the 1980s. It is urgent that spawner escapement is increased as much as possible, in order to try to reverse this negative development. But, how much can spawner escapement be expected to increase from different management actions, and how fast might these responses be? We present the results from a simple mathematical analysis of the possible effects of different combinations of increasing the minimum length limit in the yellow eel fishery, decreasing the fishing efforts in the yellow and silver eel fisheries and re-stocking small yellow eels (elvers). The results are illustrated using parameter estimates from the yellow and silver eel fisheries on the Swedish west coast (yellow eel fishery parameters according to Svedäng 1999, silver eel fishery parameter according to own guesstimate). It is shown that the present spawner escapement from the Swedish west coast is 11 % of the present possible unfished escapement. Since the present day recruitment of elvers is only about 10 % of the average recruitment in the middle of the 20th century, the present spawner escapement is only 1.1 % of the calculated more pristine maximum escapement in the middle of the 20th century. Stopping only the yellow eel fishery would increase escapement to around 8 % of the pristine level. Only stopping silver eel fishery would give around 1.5 % of pristine escapement. Re-stocking 6 million elvers, with unchanged fishing, would result in around 1.3 % of pristine spawner escapement. In order to achieve 50 % of pristine spawner escapement from the Swedish west coast a complete ban of all eel fisheries combined with yearly re-stocking of around 89 million elvers would be needed. The time perspective on spawner escapement in direct response to fishery restrictions and elver restocking is also presented. It is shown that restrictions on silver eel fishing give the fastest response in spawner escapement, followed by effort decrease in the yellow eel fishery, then length limit increase in the yellow eel fishery and the slowest response comes from restocking of elvers.

15. Response of population parameters of Atlantic salmon in the sub-arctic Teno river to the major fishing regulations and environmental effects

Dr Eero Niemelä, Jaakko Erkinaro, Sturla Brörs, Markku Julkunen, Brian Dempson, Martin Svenning, Panu Orell, Maija Länsman & Esa Hassinen

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Atlantic salmon stocks from the River Teno system have been exploited at sea with drift nets, long lines and coastal net fishing methods and in the river with net fishing methods and rods. After the drift net fishing prohibition in the coastal area of Norway salmon catches in the River Teno in terms of numbers and in weight increased in 1SW, 2SW salmon and in repeat spawners but in 3SW and 4SW salmon they declined. The size of 1SW salmon was larger during the 16 years period after the prohibition compared to 16 years before the prohibition and the size of 2SW was smaller after the prohibition indicating size selective fishing. The proportions of 1SW, 2SW and repeat spawners increased in the River Teno and in its tributaries after the drift net prohibition. The size of 1U~4SW salmon varied between 32 years considerably indicating also the importance of sea environmental effects to the growth. The significant covariations between the sizes of various sea-ages indicated the dynamics of the stocks affected by sea conditions. The size of 1SW salmon had significant correlations between the tributaries and main stem.

16. A theoretic decision analysis framework to help managing Atlantic salmon fisheries

Dr Etienne Rivot, Etienne Prévost, Eric Parent, Jean-Pierre Porcher & Jacques Dumas

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Atlantic salmon (*Salmo salar*) populations are considered as locally endangered in many rivers systems. For providing management advice, there is a need for integrating the ecological knowledge into models which help to evaluate the consequences of alternative management decisions. Because experiments on natural populations cannot easily be carried out, models can play the role of " virtual laboratories ". They allow to quantify uncertainties in management decisions. Finally, the management of natural populations aims at multi-criteria objectives. It typically looks for the best compromise between some ecological and socio-economical issues. Models can help in solving such challenging problems. The decision analysis theory provides a framework to compare the performance of alternative regulation rules of salmon rod-and-line fisheries. It was applied to the A. salmon population of the Sée-Sélune watershed (north-west of France) by the coupling of two operating models. The first one consists in an agestructured population dynamic model. The second model mimics the rod-and-line fishery in the watershed. Both models rely on data from the survey of the population and the fishery over 20 years. Fourteen fishery regulation rules were compared, including fixed harvest rate, fixed quotas and fixed escapement strategies. The consequences of each strategy in terms of conservation and exploitation were investigated via Monte Carlo simulations. A utility function was built to combine these two contradictory goals into a single criterion, which served as a basis to compare the relative performance of each strategy. The best compromise is achieved through the fixed escapement strategy. However, this strategy may be difficult to put into practice. Fixed harvest rate strategies revealed a good compromise between performance and easiness of implementation. The sensitivity of these results to some key hypotheses about both the population and the fishery dynamics are briefly discussed.

Presentations:

Session VIII MINI Symposium

“Estimation of the Reproduction capacity of European eel”

This mini symposium provides the first overview of a 3-year EU-project on eel research. The research was aimed at silvering, maturation, performance, and genetic diversity of the European eel population. The silvering process is hardly understood, and parameters for silvering were thus far rather subjective. Analyses of many morphological and physiological parameters give a strong basis for silvering, which is clearly a continuous process. New insight is obtained from artificial and physical stimulation on maturation. Swimming and high pressure both result in important hormonal responses. Changes in genetic characters were studied in relation to distribution over different locations. A novel experiment was performed in an eel farm showing *selection during growth*. *Most of the work that will be presented is not yet published.*

1. Estimation of the reproduction capacity of European eel. (Introduction)

Guido Van den Thillart

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2. Silvering of European eels; seasonal changes of morphological and physiological parameters

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Cemagref, Ecosystèmes estuariens et poissons migrateurs amphihalins. 50 avenue de Verdun, 33612 Cestas cedex, France

The downstream migration of silver eels is the last continental phase of their life cycle. Before they start to migrate downstream, eels undergo a metamorphosis called silvering. It corresponds to physiological and morphological changes that will prepare the eel for sexual maturation and for the oceanic migration back to the spawning grounds in the Sargasso Sea. During this phase, eels undergo a true metamorphosis, as many of their physiological functions are modified: those pertaining not only to sexual maturation, but also to their metabolism, osmoregulatory function, and morphology. In current literature, only two stages were considered: the growth phase (yellow eels) and the pre-reproductive phase (silver eels). However, the limit between the two was not clear, and this classification did not take into account possible preparatory stages. Moreover the migrating stage (when eels are actually able to start their migratory movements) had never been described. The aim of this study was to examine the intermediate stages and the seasonal changes of some of the physiological and morphological parameters as well as to characterize the migrating stage. In order to achieve this, a large number of eels (over 1000) were sampled at several locations (6) with different environmental characteristics (large watersheds, small coastal rivers, estuary and marsh). These eels were caught at several times of the year and with different types of

fishing gear. Biometrical and physiological sampling was carried out on each individual. Age of eels was also determined from the otoliths. Multivariate analyses were carried out on the data, and eels were clustered into several groups according to their degree of "maturation". The groups that were determined corresponded to the different stages eels undergo during the silvering process: a growth phase (stages I and II), a pre-migrant phase (III), and two migrating phases (IV and V). These were based on internal parameters such as development of gonads, regression of the digestive tract and increase in gonadotropin hormone (LH-like). The characteristics of eels at the migrating stage were compared between the different locations. A non-invasive silvering index was also calculated using Discriminant Analysis on external body measurements. Classification functions were based on body length, body weight, pectoral fin length, and eye diameters and allowed a correct classification of eels into each stage of 82%. This study gives a thorough description of the silvering process, as well as a standard non-invasive method to determine whether an eel is physiologically ready to start its migration. This work was supported by European Commission, project (EELREP, Q5RS-2001-01836).

3. Energetics of eel migration; swim fitness and swim capacity

1- Guido van den Thillart¹, Arjan Palstra¹, Csaba Zsekely², and Vincent van Ginneken¹

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European eels migrate great distances to reach their spawning sites. As silver eels they leave the European West Coast in the fall and are supposed to reach the Sargasso Sea after about 6 months. The distance they have to cover is about 6000-km, which means for an 80-cm female eel (1.5-kg) a swimming speed of about 0.5 BL/s. Characteristic for silver eels is that they stop feeding when they start migrating down the rivers between August and October (Dutch situation). Eels have much fat as energy stores. As they have to cover a large distance, the cost of transportation (COT) is a crucial factor. Calculations show that when they swim at a similar COT as salmonids, eel would be incapable to cross the ocean. So, a high fat content as well as a low COT value determines whether they can cross the ocean and how much energy remains for maturation. In order to be able to study the energetics of long-term swimming a set-up with swim tunnels was constructed. The flow in the swim tunnel was validated by a Laser-Doppler system. With this set up we have shown that large female eels (80-cm) can swim continuously at 0.5 BL/s during 6 months covering a distance of 5500-km. The oxygen consumption rates remained stable at 36.9 ± 2.9 mg/kg/h over the 6-months swimming period for all tested eels. The mean cost of transportation was 28.2 mg O₂/kg/km. From the oxygen consumption as well as from the weight loss similar values for COT were obtained. The COT value of eel is 4-6 times lower than salmonids. This together with a high fat content seems crucial for the eel's capacity to cross the Atlantic Ocean. Apart from long term swim trials, we have tested silver eels from different locations for their swim capacity. Eels were obtained from Lake Balaton, the Loire, Lake Grevelingen, and from a Dutch eel farm. Short term and intermediate endurance tests revealed the same results: eels swim at a rather constant COT between 0.3 and 1 BL/s. Their maximal endurance speed is around 2 BL/s, which is low compared to other fish species. Swim fitness tests showed differences between eels from different locations and a reduction of the fitness by infection with swimbladder parasite.

This work was supported by the Foundation for Technical Research (STW, LBI.4199), and the European Commission, project (EELREP, Q5RS-2001-01836).

4. Natural and artificial induction of maturation of European eel

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Swimming and maturation are two key elements of the reproduction capacity of eel. Dufour (1994) demonstrated a prepubertal blockage of further maturation in silver eels. Multiple environmental factors are hypothesized to be involved in deblockage. In this study, we carried out two types of experiments to elaborate the induction mechanism. First we investigated the role of swimming exercise in deblockage by simulated short and long term migration. Second by long term hormonal stimulation we were able to induce final maturation and produce prehatching embryo's. Already after a week swimming, yellow eels from Lake Balaton show significant increase of gonadosomatic index and oocyte diameter. The eyes were increased and the digestive tract decreased. None of these showed further change between two weeks and two months swimming. After six months swimming GTH-2 in the pituitary, plasma estradiol and oocyte diameter had increased in farmed eels. So, we may conclude that swimming induces silvering as well as maturation. In three independent experiments, we artificially induced maturation of 200 male and 82 female European silver eel from Lake Grevelingen (the Netherlands) and Loire River (France) with respectively Human Chorionic Gonadotropin (HCG) and Carp Pituitary Extract (CPE). Ovulation was induced using DHP. During final maturation, biopsies of the ovary of individual females were regularly checked for histological changes of oocytes. After 9 weeks of treatment, males released high motility sperm (80-90%). Fifty females fully matured after 11-25 injections having a GSI of 28-60. No difference in response was found between Lake Grevelingen and Loire females. Twenty-four females were induced with DHP and ovulated between 10-24 hours after injection and were hand-stripped. Of eighteen of these females, the eggs were fertilised as shown by the occurrence of cell divisions. The fertilised eggs of two females developed into 1600 embryos that stayed alive for more than four days. In contrast to Japanese eel (Ohta et al., 1996) European eel showed clearly a slower and more individual response to injections with CPE. The moment of stimulation of final maturation and ovulation is mainly based on weight increase related to the hydration response which, in European eel, appears unreliable. As the developmental index of oocytes predicts oocyte sensitivity, a new protocol based on the developmental stage of oocytes may result in successful reproduction of European eel.

Dufour, S. 1994. Bull. Fr; Pêche Piscic. 335: 187-211.

Ohta H, Kagawa H, Tanaka H, Okuzawa K, Hirose K, 1996. Aquaculture 139, 291-301.

This work was supported by European Commission, project (EELREP, Q5RS-2001-01836).

5. High pressure resistance and adaptation of European eels

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During its life cycle, the European eel (*Anguilla anguilla*) has to migrate for reproduction. As the supposed breeding area is located in the Sargasso sea, that means that the eel must perform a long travel from the European rivers, where it lives at the yellow then the silver stages. In addition to the energy costs of osmoregulation and temperature changes, the migration corresponds to a long swimming activity which requires a lot of energy, most of which being consumed by red muscle through the aerobic pathway. In fact, migration is performed at depth *i.e.* at high hydrostatic pressure (HP). This last is known to alter energy metabolism in fish. By modifying membrane fluidity and/or membrane components, HP alters the functioning of respiratory chain and the associated oxidative phosphorylation. However, acclimatization to these effects is possible. During the nineties, it has been shown that, by recruiting more unsaturated fatty acids in its membranes, yellow eel is able to restore membrane fluidity and thus aerobic energy metabolism leading to a more efficient oxidative phosphorylation. However, since about 1990, a dramatic decline in eel population is observed. Are the human activities only responsible and/or is there exist an alteration in eel fitness? Are the eels differently affected depending on their location? Resistance to HP has been evaluated in silver eels from different locations in Europe by testing mitochondrial functioning. The results show that pressure resistance depends on the eel's origin and maximal aerobic capacities

are differently decreased. Consequently, reasoning on the basis of total energy budget, it appears that energy cost of swimming under pressure can represent from 30 to 65% of the maximal available aerobic power. When the energy cost of swimming under pressure is too high, this leaves few energy available for other tasks mainly reproduction. The silver eels which have a high pressure resistance are evidently able to acclimate to HP (one month at 101 ATA) and this, much more easily than makes the yellow eels. The hypothesis is thus raised that silvering process, which takes place at atmospheric pressure, has the same physiological effects than pressure acclimatization for yellow eels and thus prepares the fish for migration at depth.

This work was subsidized by the European contract EELREP N° Q5RS-2001-01836.

6. Suppressing maturation as a requirement for eel long distance migration : neuroendocrine mechanisms and implications for induced maturation

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Silvering prepares the future eel genitors to the oceanic reproductive migration and also includes a slight stimulation of early stages of gonadal development. However, this activation is very limited and further gonadal development never occurs in natural continental conditions. The extent of gonadal development reached at the silver stage varies according to *Anguilla* species, with a possible correlation to the respective distances between continental habitats and spawning grounds. The European eel, *Anguilla anguilla*, presents one of the lowest gonadal development at the silver stage, likely related to its remarkably long oceanic migration to Sargasso sea. Gonadal development and gametes production in the silver eel can be induced by gonadotropic treatments (hCG in the male, carp or salmon pituitary extract in the female) as shown by the pioneer work of M. Fontaine and coll (1936, 1964). Even if these discoveries opened the way to decades of experiments on induced maturation in the Japanese eel, *A. japonica*; much less work had been performed in the European eel. Furthermore, maturation in response to exogenous gonadotropic treatments seems much less successful and more variable in the European eel than in the Japanese one. Raising new data on the maturation mechanisms and capacity of the European eel is of crucial interest, in view of the dramatic decline of its stocks. A line of investigation concerned the evaluation of individual variations among female silver eels in the response to gonadotropic treatments. These data provided new criteria for reproductive capacity of future genitors to be applied for conservation (protection and improvement of the quality of future genitors in European hydrosystems) and for aquaculture (selection of genitors for trials of artificial maturation). Another line of research concerned the analysis of the neuroendocrine mechanisms of suppression of reproduction in the eel. They revealed a dual brain control of eel pituitary gonadotropic function, positively by gonadoliberin and negatively by dopamine, with a key role of dopamine in the blockade of eel maturation. These data may lead to new strategies to induce maturation, by stimulating the eel brain-pituitary axis, instead of directly stimulating the gonads: - treatments with neurohormones to stimulate eel endogenous pituitary gonadotropic function; - submission to environmental factors (possibly encountered during oceanic migration or/and at the spawning ground) to activate the brain-pituitary axis. The role of other endocrine systems involved in the metabolic needs of maturation, such as mobilisation of calcium stores from vertebral skeleton during vitellogenesis, was also investigated. These data provide new biological bases and new strategies for the conservation of wild eel stocks in European hydrosystems as well as for future development of artificial reproduction in aquaculture.

This study was supported by a grant from the European Community (EELREP N° Q5RS-2001-01836)

7. Possible causes for the decline of European eel population

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Worldwide, eel populations have been dwindling over the last decade. The exact cause for this phenomenon is unknown but possible causes include: PCB's, viruses, swimbladder parasites and diminished fat stores. In order to study whether these factors had effect on the swimming performance and endurance of European eel, experiments were performed in 22 large swim-tunnels of 127 liter in the laboratory. We found that eels loaded with a known amount of PCB's had significantly lower oxygen consumption after 750-km in comparison to a control group. For swim bladder parasites a negative correlation was found between infection pressure and optimum swim speeds. Higher densities of parasites cause a decrease of maximal sustained speeds at which eels could cruise to the Sargasso. A negative correlation was also found between swim bladder length and cost of transport. Parasites cause the swimbladder to shrink resulting in higher costs of transport. Thus overall, swimbladder parasite reduces cruise capacity. EVEX (Eel-Virus-European-X), HVA (*Herpesvirus anguillae*) and EVE (Eel Virus European) were detected in wild and farmed European eels (*Anguilla anguilla*) from the Netherlands, EVEX and EVE from farmed eels from Italy and EVEX from wild eels from Morocco. EVEX was also isolated from wild New Zealand eel (*A. dieffenbachi*). Elvers (*A. anguilla*) collected from eel farms in the Netherlands were mainly infected with HVA. We show in large swim tunnels that eels infected with EVEX developed hemorrhage and anemia during simulated migration, and died after 1,000-1,500 km. In contrast, virus-negative animals swam 5,500 km, the estimated distance to the spawning ground of the European eel in the Sargasso Sea. The virus-positive eels showed a decline in hematocrit, which was related to the swim distance. The virus-negative eels showed a slightly increased hematocrit. The observed changes in plasma Lactate dehydrogenase (LDH), Total Protein and Aspartate aminotransferase (AST) are indicative of a serious viral infection. Long term swim experiments over 5,500-km with European eel demonstrate that eels are very efficient swimmers. Diminished fat stores due to insufficient food supplies in the inland waters are possibly not impair the crossing of the Atlantic because they are very efficient swimmers with energy cost for migration 4-6 times lower than salmonids. Still, the initial lipid stores will determine how much energy remains for reproduction. Based on all these observations, we conclude that possibly not one cause but several causes affect the spawning migration of eels, and could be a contributing factor to the worldwide decline of eel populations.

This work was supported by the European Commission, project (EELREP, Q5RS-2001-01836).

8. Genetic variability of the European eel population

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Silver and glass eel samples collected in 2001, 2002 and 2003 at five locations throughout the geographic range of European eel were screened using 13 allozyme and 8 microsatellite loci. The survey shows a subtle genetic differentiation, which is however not stable over consecutive years. The differentiation depends probably on oceanic/ environmental factors and reproductive success. Unlike glass eels, silver eels show isolation by distance and isolation by time. Both morphological and genetic structure shows a strong variation throughout Europe over time in glass eels, while silver eels show a fairly constant morphological pattern in successive years. A small-scale temporal genetic analysis consisted of analyzing independent "arrival waves" of glass eels. Sixteen different "arrival waves" were collected in 2001, 2002 and 2003 in The Netherlands, South-Western France and Eastern Spain, including a total of 1076 individuals. Samples have been screened for genetic variation using 13 allozyme and 8 microsatellite loci. The analysis reveals similar levels of genetic variability across samples and a limited genetic differentiation. Partitioning of genetic differentiation shows temporal differentiation to be more important than geographic differentiation. When partitioning temporal differentiation, more differences were found within-years than between-years. Both allozyme and microsatellite data suggest that attention should be paid to within-year variation since the largest differentiation is found between "arrival waves" in the same location. In an experiment designed by the commercial partner Ryaal bv and the KULeuven, glass eels have been successfully grown in two separate batches during one year. Genetic samples of glass eels were collected from each batch at the start of the experiment and after one year in the facilities. Samples were genotyped using both allozyme (selection-sensitive) and microsatellite (neutral) markers to test for the effect of natural selection. One

batch has been monitored for another 12 months. Individuals grown for one year at the farm presented a differential growth rate that produced a substantial range of sizes, including small (slow growth), large (regular growth) and fast-growth individuals. We tested for a possible correlation between growth – measured as length and weight increase – and genetic variability – measured as multilocus heterozygosity (MLH) using 13 allozymes and 8 microsatellite loci. When comparing levels of genetic variation, fast-growth individuals show the highest genetic variation in comparison with slow or regular growth individuals. Significant positive correlations are observed between MLH / length increase and MLH / weight increase. Results provide evidence for a positive correlation between genetic variability and growth rate in the European eel. More heterozygous individuals show a significantly greater length and weight increase and a higher condition index in comparison with more homozygous individuals. In conclusion, our results provide good evidence for a heterozygosity fitness correlation in farmed European eel individuals. Multi-locus heterozygosity is positively correlated with growth, so that individuals attaining a larger size presented a higher genetic variation in comparison with smaller individuals. This work was supported by European Commission, project (EELREP, Q5RS-2001-01836).

9. Reproduction capacity of European eels (Synthesis)

Sylvie Dufour

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Poster presentations:

“Biogeography at Continental and Regional scales”

1. Allis shad *Alosa alosa* (Linnaeus, 1758) in the Baltic Sea: occurrence and morphometric characteristics in comparison with twaite shad *Alosa fallax* (Lacepede, 1803)

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The historical and recent status of Allis shad in the Baltic Sea is described, from published and yet unpublished data as well as from museum collections of the Baltic Sea area. Specimens from museum collections were also subject to a biometric analysis. Many catch records of Allis shad found in the historical German literature are incorrectly classified. This is due to the existence of parallel local German names, which did not allow to distinguish correctly between Allis shad and twaite shad. This was the main reason why LADIGES & DUNCKER (1960) came to the wrong conclusion that Allis shad does not occur in the Baltic Sea. Nowadays reliable historic records of catches of Allis shad in the Baltic Sea from the coast of Sweden and Finland are available. Specimens were caught in the 1990ies near the Swedish, Danish, German, and near the Polish Baltic Sea coasts. One record stems from the lake Vänern (Sweden). The historical and recent records are widely scattered, both, in their geographical position and in time. Since there, there are doubts that these individuals belong to a homogenous Baltic Sea population they are considered as occasional visitors from outside. A total of 11 specimens mainly from the zoological collections of Stockholm and Copenhagen museums of Allis shad were examined for morphometric characters. In the analysis are involved 20 metric and 6 meristic characters. For comparison the same procedure was performed on twaite shad specimens from the Baltic sea. The results are presented and discussed in comparison with already published biometric data.

2. Recent studies of Sea lamprey (*Petromyzon marinus* L.) in Irish rivers: findings and conservation implications

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The status of anadromous sea lamprey, *Petromyzon marinus*, has been examined, over the period 2000 - 2004, in a number of large Irish rivers. These rivers have been designated under the EU Habitats Directive as candidate Special Areas of Conservation. The aim of the studies was to develop a baseline to inform measures to ensure favourable conservation status for this species. Spawning effort, as determined by counting of redds, appeared to be at a low level in many cases, although major fluctuations were recorded between years. Counts on the R. Nore SAC rose from 48 redds in 2000 to 115 in 2001, over the same 48 km section of channel. Spawning locations were frequently associated with the downstream side of major weirs. However, distribution of juvenile *P. marinus* was more widespread, indicating that, at least in some years, adult fish were able to pass major weirs and spawn upriver. Sea lamprey ammocoetes were extremely rare in the Slaney SAC and were generally confined to the lower reaches of the Moy SAC. On the other hand, ammocoetes were more widespread in the Munster Blackwater, where samples were collected in headwater areas, over 100 km from the upper tidal limit. Juvenile sea lamprey, when found, generally represented a small proportion of the total ammocoete population encountered at a site. This was as low as 0.92% or 0.25 fish / m² at a series of replicates in the Slaney system but frequently exceeded 30% in the Munster Blackwater main stem with density values of 1 - 9.3 fish / m². The length frequency data indicated a disparate population structure among juvenile sea lamprey with many year classes absent in the majority of channels. Young-of-year ammocoetes were infrequently captured. The findings give cause for

concern as to the size and viability of Irish populations in some of the SACs studied and possible conservation management aspects are examined.

3. Distribution of river and sea lampreys in German waters of the Baltic Sea

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In general there is a lack of information regarding the distribution of anadromous lampreys in European marine habitats including the Baltic Sea. The present occurrence of lampreys in German waters of the Baltic Sea was investigated via a research fishery with otter trawls. Fish sampling was carried out between the Islands of Rügen, Usedom and Bornholm in the Exclusive Economic Zone of Germany and in coastal waters of the Usedom Island during autumn 2003 and in spring, summer and autumn 2004. A total of 121 hauls was performed. Additionally, catch records of lampreys were contributed from fisheries research institutes. In order to obtain information regarding the historical occurrence of lampreys, the ichthyological collections of 7 relevant institutions and historical catch statistics were analysed. Furthermore, an information sheet containing drawings with the most important determination characteristics of the species was developed. This information sheet was distributed to a group of select reliable fishermen along the Baltic coast of Germany. From 1822-1999 the highest number of records of river and sea lampreys was obtained from the waters around the Rügen Island, from the Szczecin Lagoon with adjacent waters, from the mouth of the Warnow River, from the Mecklenburg Bight and from the Kiel Bight indicating the importance of these waters as habitat for lampreys during that time. Important lamprey stocks existed also east of these areas. From 1900-1920 about 27085 kg of river lampreys were caught annually in the Gdańsk Bay, Vistula Lagoon and -KurŻiu Lagoon. More than 80 individuals of river lamprey but only 4 individuals of sea lamprey were recorded in German Baltic waters from 2001-2004. Most of the individual records of river lamprey originated from the Szczecin Lagoon and its adjacent waters, demonstrating the importance of these water bodies for the spawning migrations of this species. In comparison, only 4 single individuals of sea lamprey were caught at 4 different locations in German Baltic waters. Nowadays, no actual reproduction of sea lamprey and no regular annual spawning of river lamprey are known from the German Baltic Sea area.

4. Biometric analysis of geographic variation of sea lamprey ammocoetes in the main Portuguese river basins

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This study concerns the biometric comparison of sea lamprey (*Petromyzon marinus* L.) ammocoetes populations in seven Portuguese hydrographical river basins: Minho, Lima, Cávado, Vouga, Mondego, Tejo and Guadiana. Specimens were analysed in terms of morphometric (i.e. head length, trunk length) and meristic (i.e. head, trunk and caudal myomeres) characters in order to investigate the hypothesis of population fragmentation along the Portuguese river basins. The differences between the ammocoetes Fulton's condition factor (K) of the different populations were explained with a highly significant multiple linear regression ($R^2_{adj} = 0.96$), where the water physicalchemical characteristics, namely, water temperature, conductivity, suspended solids and dissolved oxygen, were the environmental parameters that entered the model. The discriminant analysis showed a morphological segregation of the studied populations based on the head length and branchial length; and the meristic analysis presented a segregation resulting from differences observed in the number of trunk myomeres. This study showed that the ammocoetes from rivers Minho, Lima and Tejo presented the largest cephalic region, in comparison to the other studied populations, which may result in a better feeding efficiency and, consequently, higher values of K. The meristic results contradict the general rule, that in the northern hemisphere the number of meristic elements is progressive higher to the north, which can be explained by different genetic backgrounds and by unique characteristics of the reproduction site in each river.

5. Migration dynamics of clupeids in the Scheldt estuary: a stable isotope approach

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The way fish exploit estuaries remains poorly understood due to the complexity of life cycles. One way to elucidate spatiotemporal patterns of migrating organisms is by using their stable isotopic composition as a natural intrinsic marker. In this study the migration dynamics of Clupeids between the North Sea and the Scheldt estuary were examined using C and N stable isotopes. Large numbers of young-of-the-year herring (*Clupea harengus* L.) and sprat (*Sprattus sprattus* (L.)) typically enter and remain within North Sea estuaries during the winter months. From May 2000 to April 2001 fish were collected monthly in the upper and lower estuary. White muscle tissue and stomach contents were analysed for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ using a CF-IRMS. Stomach contents were applied to isotopically characterise the food webs at the two sampling points. The average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ value of the marine food web was respectively $U^{\circ} 20.93 \pm 1.38\text{‰}$ and $+15.31 \pm 1.34\text{‰}$, and were relatively stable. Similarly, $\delta^{13}\text{C}$ of Clupeid prey in the upper estuary was also relatively stable ($-28.05 \pm 1.36\text{‰}$), but $\delta^{15}\text{N}$ varied considerably, averaging $+16.04 \pm 4.93\text{‰}$. It was shown that $\delta^{15}\text{N}$ could not be used as a tracer because the longitudinal $\delta^{15}\text{N}$ -gradient had reversed completely during the year. The $\delta^{13}\text{C}$ -gradient, however, was found to be reliable and applicable to study fish migration in the Scheldt estuary. Seasonal movements of Clupeids in the Scheldt estuary were analysed by decomposing the temporal abundance patterns into migration components based on their muscle isotopic composition. Recently immigrated fish from the North Sea, displaying typical marine $\delta^{13}\text{C}$ -values, were distinguished from individuals already resided in the estuary and who were characterized by estuarine $\delta^{13}\text{C}$ -values. Immigration and emigration occurred continuously throughout the year. Net upstream immigration peaked in November. During winter immigration persisted, though with decreasing intensity which attributes to the lower fish abundance recorded in the inner estuary. Although the abundance of herring and sprat further declined in February and -March, net seaward emigration was not demonstrated.

6. Sturgeon reintroduction in the Rhone river: problematic and preliminary works

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Sturgeon is extinct in the Rhone river since 1975 (Tabardel 1994). This sturgeon reintroduction project in the Rhone river deals first of all with sturgeon specie(s) identification using archeozoology and genetic. As no living specimen of Rhone sturgeon is available, preserved specimens (museums) and bones from an archeological deposit (2500 pieces from Arles) will be used for determination. Former controversial works in Spain (Garrido-ramos *et al.*, (1997) ; Elvira and Almodovar (2000)) asses that Adriatic sturgeon, *Acipenser naccarii*, lived in Spain in addition with European sturgeon, *Acipenser sturio*. By extension, one can imagine that these species were living in the Rhone river. As there is controversy, a clear identification of the sturgeon specie(s) formerly living in the Rhone is essential. The only stock available for European sturgeon reintroduction comes from a small ex-situ stock from the critically endangered last world population for this specie in the Gironde watershed (France). This ex-situ stock is aimed at providing larvae for reintroduction. This stock could allow larvae stocking in the next 3 to 5 years. Concerning the Adriatic sturgeon, the last natural population inhabits the Po river (Italy) but some huge stocks exist in fish farms in Italy as in Spain. This could allow a quick massive stocking if it appears that this specie was living in the Rhone river. In parallel, a study concerning habitats availability and quality in the open Rhone will be done to be sure that this river is suitable enough for a self sustainable sturgeon population. This project is only the first step of a bigger one that could lead to the writing of a reintroduction plan in the Rhone river.

Poster presentations:

“Diadromous fish in Ecosystems”

1. Habitat preferences of larval *Petromyzon marinus* (L.) and *Lampetra* sp. in rivers of Gironde Dordogne basin

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To be effective in conserving lamprey populations, the larval habitat of lamprey *Petromyzon marinus* and *Lampetra* sp. has to be known. The pattern of habitat preferences was examined in 4th order rivers Livenne, Cère, Dronne and in the 6th order river Dordogne (France). From shallow waters to deepwater areas, the same dredging technique was used while diving to catch burrowing larvae. Sampled sections of rivers were chosen downstream of one spawning ground at least and sampled plots over a range of macrohabitats. An inverse relationship was observed between density and length of larvae. Larval distribution was patchy throughout the sections. Larvae aggregated at sites presenting a soft river bed (pool, backwater pool, alcove pocket water, downstream of an obstacle to the water flow). Water depth was not found to be a significant variable. Burrowing larvae distributions were strongly dependent upon particle size composition (mixture of median and coarse sands). Sands were systematically dominant and some organic matter was always present (respectively 64 to 100%, 0.2 to 18.3% dry weight). Both *Petromyzon* and *Lampetra* larvae occurred in sediment with a 0.6 mm average diameter of particles. Microhabitat use between small and large sized larvae (< and > 60mm) indicated the same capacity to sometimes use a more heterogeneous substrate. In the Dordogne river, sandy tributary junctions influenced the distribution of *Lampetra* larvae. Cumulating data of the four rivers, the probability of ammocoete occurring within their preferred habitats was low (45%) and very low (10%) within other habitats. Downstream spawning grounds, aquatic vegetation and coarse woody debris on hard river bottoms (gravels, pebbles) could strongly increase habitat for young of the year thanks to the deposition of flocculent. These facts should contribute to directing attempts at river habitat conservation of these vulnerable species.

2. A 12-year study of the upstream migration of *Anguilla anguilla* in a fish-pass in the River Meuse reveals a dramatic decrease of the stock in Belgium

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From 1992 to 2004 upstream migrating eels were collected in a trap (0,5 cm mesh size) installed at the top of a small pool-type fish-pass at the Visé-Lixhe dam (built in 1980 for navigation purposes and hydropower generation; height : 8,2 m; not equipped with a ship-lock) on the international River Meuse near the Dutch -Belgium border (290 km from the North Sea; width: 200 m; mean annual discharge: 238 m³/s; summer water temperature 21-26°C). The trap in the fish-pass was checked continuously (three times a week) over the migration period from March to September each year, except in 1994. We caught a total number of 32157 eels (biomass 1,955 kg) with a size from 14 cm to 85 cm and a mean value of 31,6 cm corresponding to yellow eels. The study based on a constant year-to-year sampling effort revealed a regular decrease of the annual catch from a maximum of 5613 fish in 1992 to a minimum of 423 in 2004. This demographic trend is fitted by the equation: number per year = 5.614 - 299 t, where t is time in years with 1992 as year 1. According to this model, the upstream migrating yellow eelstock in the Belgian Meuse should drop to near zero within the next ten years, as an expression of a collapsing recruitment of glass eels in the estuary in the Netherlands. In the discussion of these results, we examine the possible role of two other factors on the decrease over time of the number of yellow eels caught in the fish-pass. i) the effect of environmental variables (river discharge, water temperature and dissolved oxygen content) on the timing and intensity of upstream migration waves and ii) the existence and use of alternative migration routes.

3. Comparative study on the methodologies used for the determination of age and growth in sea lamprey ammocoetes (*Petromyzon marinus* L., 1758) in the Mondego river basin Portugal

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The present study summarizes some of the work on the determination of age and growth in ammocoetes of sea lamprey (*Petromyzon marinus* L.) that has been carried out for the past 6 years in the Mondego's river basin, in Portugal. Through this period of time, various methods were used: length-frequency distributions, reading of statoliths and animals injected with oxytetracycline (OTC) maintained in cages on the river. It was estimated, according to the length-frequency distribution for this population, a seasonal Von Bertalanffy growth formula, whose parameters were 198.5 mm (TL), 0.7 year⁻¹(K), 0.8 (C), 0.1 (WP), 130 mm (SL) and 13 (SS). The age of the ammocoetes and the theoretical expression of these animals' growth were also evaluated through an innovative approach, combining the reading of statoliths to digital image analysis. The statoliths, although providing more reliable age estimates than the length-frequency distribution analysis, are quite difficult to read and also imply the sacrifice of the animals. Nevertheless, the use of this method makes possible, not only the evaluation of age with just a single sample as well as the back-calculation of length at age, from the reading of the ammocoetes' statoliths. The latter procedure assigned a mean total length of 82.07mm (s 11.99), 117.90mm (s 12.52), 148.40mm (s 13.57) and 158.72mm (s 14.54) to, respectively, the 1+, 2+, 3+ and 4+ age groups, which was consistent with both the count of the number of annuli present in the statoliths and the results from the length-frequency distribution analysis. During the last year, 150 ammocoetes marked individually with decimal coded wire tags (DCWT) were kept in this river in cages in order to study their growth in the wild. The animals of two of those cages had also a chemical tissue marker, oxytetracycline (OTC), to validate the method.

4. Factors ruling distribution and abundance of the European eel, *Anguilla anguilla*, in the Mondego river (Portugal)

Pr Isabel Domingos & José Costa

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The distribution and abundance of the European eel, *Anguilla anguilla* (L.), in relation to environmental variables were investigated in the Mondego River, a strongly modified river located in the center of Portugal. Eels, monthly caught by electrofishing during a period of two years in nine freshwater sampling sites, were strongly affected by certain anthropogenic factors which played an important role in their distribution and abundance in this river. Multivariate statistical analysis revealed that river width, number of obstacles, maximum depth and distance to the river mouth were the most relevant variables ruling population structure and abundance in River Mondego. Despite less associated with habitat preferences, river flow and water temperature did also explain this species' patterns of distribution. Small eels (< 15 cm) preferred wider and deeper river stretches while larger eels (> 15 cm) were more tolerant to increasing river flow and lower temperatures and more abundant in upstream locations above a series of obstacles. Environmental variables strongly associated with habitat characteristics and/or anthropogenic constraints versus temporal variations are discussed and the conflict with migratory needs is emphasized.

5. Annual variation in spatial and temporal migration of wild Atlantic salmon smolts determined from a video camera array in the sub-Arctic River Tana

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Spatial and temporal migratory behaviour of wild Atlantic salmon smolt (*Salmo salar* L.) was investigated annually from 2002 to 2004 in a tributary of the large sub-Arctic River Tana, using submerged video cameras positioned horizontally and vertically such that the entire water column across the river was observed. This is the first study to provide detailed information on the exact time, position in water column, and swimming direction of individual salmon smolts. The earliest smolt migration started at the beginning of June (2002) while the latest run (2004) ended in late July, i.e. during the period of midnight sun. The number of smolts was twice as high in 2004 compared to the two previous years. In contrast to other studies, we found that the smolt migration was both nocturnal and diurnal, with most smolts migrating during daytime. Hours of sunshine and change in water level explained most of the day to day variation in numbers of migrating smolts. Most smolts migrated actively (head first) in the middle of the river and in the deepest part of the water column. Less than 5 % of the smolts used the upper 30 cm of the surface water layer.

6. Migration and growth of tagged summer Vistula sea trout smolts released into the lower Vistula River

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In 1968 the Vistula River was dammed in Wloclawek, 266 km up from the river mouth. This dam interrupted the migration of sea trout spawners for spawning. The aim of the work was to gather information on migration, growth and effectiveness of stocking of sea trout smolts. In 1972 - 1977, 16,985 two year old tagged smolts were released into the lower Vistula River, 74 km up from the river mouth. A total of 1,696 recovers (10 %) were obtained. The released smolts migrated to the sea immediately after their release and the fastest migrating smolts reached the sea after 3-5 days, which indicates that they migrated at a speed of 37 km per day. The Vistula sea trout were observed in all parts of the Baltic Sea. They were most often caught in the Vistula mouth (35.1 %) and in the sub-division 26 (32.5 %) as well as around the Gotland Island. A lot of tagged fish were caught in the Vistula River (15.2 %). Some of them were caught below the Wloclawek dam (1.1 %) - 266 km from the mouth. Sea trout were exploited during 5 years. Most of the fish were caught at ages A.1+ (65.7 %). Fish of ages A. 0+ and A. 2+ were obtained at rates of 15.6 % and 14.6 %, respectively. The greatest numbers of tagged fish entered the Vistula River during summer months. In the first year after the release sea trout specimens reached average lengths of 51 cm and weights of 1,523g, while in the second year - 69.6 cm and 4,356 g and in the third year - 78.7 cm and 6,036 g. The effectiveness of stocking was correlated with the percentage of recovers. It was highest for smolts when average percentage of recovers reached 10.6 %. It was 395 kg from 1,000 released smolts, but in cases of low percentage of recovers e.g. 1.4 %, then the effectiveness was only 47.9 kg.

7. Relation between continental hydro systems and silver eels fractions: a typological analysis needed for eel stock management

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Despite a crucially urgent demand, by managers and stakeholders from local to national and European levels, addressed to scientists, there is still little information about the production of silver eels by continental waters. So a reflection on the variability of reproduction potential is proposed of different fractions of silver European eels (*Anguilla anguilla*). In fact, considering the large spatial distribution and the division of the European eel stock that exists in fragmented subpopulations, strategy for conservation can only be taken within the scattered conti-

mental waterbodies. We investigated the reproduction potential of silver eels in three different waterbodies in France: the Loire where a mark recapture experiment is conducted with the collaboration of professional fishermen, the Frémur River a highly impacted short river system, and the Oir a small river in a relatively pristine state. We compared the reproduction potential of these three types of hydrosystem by estimation of prespawners production (eels trap and CMR method), analysis of life-history traits (sex ratio, age/length at maturity and growth) and quality of eels (condition factor, GSI). Moreover, among the numerous factors that may alter breeding success of eels, we focused on the impact of *Anguillicola crassus* in the swimbladder and water pollution. Our results showed that breeders from different areas do not have the same chance to succeed their reproduction. Although the contribution of the different watersystem in term of number of breeders produced is a major component of a conservation strategy, the latter must be counterbalanced by the quality of them. We concluded that a typology of hydrosystems, included their efficient contribution to the breeding stock, is necessary to fixed relevant management orientation.

8. Habitat selection of ammocoetes belonging to the genus *Lampetra* in the Tagus River basin, Portugal

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The purpose of this work was to identify which environmental factors affect the distribution of *Lampetra planeri* and *L. fluviatilis* ammocoetes in the Tagus River basin, particularly in two tributaries, rivers Almansor and Erra. In the present study we worked at the genus level because the specific status of these two species is uncertain and also because these species are not easily distinguished in the larval phase. Multiple regression analysis was used to test the variables against the total abundance of ammocoetes and canonical correspondence analysis was used to test the same variables against the abundance of ammocoetes lengthclasses. In the River Almansor the total abundance of ammocoetes was positively related with a permanent water regime and negatively related with areas occupied with intensive agriculture activities, as well as areas where the percentage of coarse sand was higher. In terms of length-classes, the smaller individuals preferred areas with higher quantities of dissolved oxygen and higher shading percentages. Medium length ammocoetes were captured in sites with higher percentages of emergent vegetation and with presence of leaf debris in the stream bed. The larger individuals occupied areas with higher current velocity. In respect with granulometric composition of the river bed and total organic matter content, the smaller individuals preferred areas with higher organic matter percentage with fine particle sediment whereas larger ammocoetes occupied areas with coarser sediment. In River Erra the total abundance of ammocoetes was positively related with current velocity and with higher values of IBI (index of biotic integrity using fish communities) and negatively related with QBR (index of riparian quality). In terms of length-class distribution, the smaller individuals were found in areas closer to tributaries, with higher percentages of filamentous algae, higher values of QBR and areas without the presence of sand extraction activities. The medium and large length ammocoetes preferred sites with presence of wood debris. The latter length-classes also preferred areas occupied with extensive agriculture activities. The relationship between length-class of ammocoetes and granulometric composition of the river bed and total organic matter content in Erra watershed was similar to that obtained for the River Almansor. These results indicate that ammocoetes of *Lampetra* sp. (specially smaller length classes) occupy preferably, areas protected from environmental fluctuations and where human activities are less intense.

9. Influence of developmental environment on natural stream adaptation in Atlantic salmon, *Salmo salar* L., juveniles

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Within the framework of a research program on the quality of hatchery-reared young Atlantic salmon, the natural stream adaptation of different salmon groups was studied in relation to their developmental conditions. We tested the hypothesis that the adaptation and settlement in the wild depended mainly of the early experience and learning acquired by young salmon during ontogeny in their first developmental environment, whether natural or artificial. The implementation of experimental tests focusing on behavioural ecology factors showed that young

salmon, particularly those reared during several months in artificial environmental conditions (hatchery), were more gregarious and territorial than wild conspecifics. Experimental tests were conducted in two identical sections of a flume offering a range of microhabitat choices with or without predators. Similar experiments were performed at a larger scale in an outdoor stream channel. In order to examine fry learning capacities for a better settling in the natural environment, "reconditioning" trials of hatchery fry were conducted using a short stay in a semi-natural experimental stream channel or a modified hatchery rearing tank including visual marks on the bottom and an improved water flow and feed delivery system. In comparison to their wild conspecifics, these "reconditioned" fry modified their swimming behaviour and habitat choice and became more able to fight against water flow and avoid predators. Similar experiments performed in the natural environment allowed to validate the results in terms of survival and growth.

10. Lampreys of Iberian Peninsula: distribution and conservation status

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There are 34 lamprey species in the Northern Hemisphere, of which three are recorded in the Iberian Peninsula (IP): *Petromyzon marinus* and *Lampetra fluviatilis* which are anadromous and parasitic when adult, and *Lampetra planeri* which is non-migratory and non-parasitic and is thought to have evolved from the anadromous form. In the Red List of Portuguese vertebrates (SNPRCN, 1991) the two species of *Lampetra* are classified as "Rare" and *P. marinus* is considered "Vulnerable". In Spain, *L. fluviatilis* is virtually extinct and *L. planeri* has only been recorded in a small northern river near the Pyrenees. *P. marinus* is still present in a few rivers in Galicia and in the south of Spain in the Guadalquivir river basin (Doadrio, 2001). All three species of lampreys are listed under annexes II and V of the Habitats Directive. They are designated in the European Union (EU) Habitats Directive as species requiring conservation within member states. The Red List for fish and lampreys of Sweden, Poland, Slovenia and Wadden Sea classified these species as endangered. This work has the purpose of providing conservation guidelines with regard to these species in the Iberian Peninsula (IP). To achieve this objective a preliminary field survey was done to establish the current distribution of these lamprey species in the IP. Electrofishing was carried out in main rivers of Portugal to get information on the distribution and abundance of the three species. *Lampetra sp.* distribution in Portugal is confined to the regions between rivers Esmoriz and Sado, whereas *P. marinus* occur in almost all major rivers (Minho, Cávado, Lima, Ave, Vouga, Mondego, Tagus and Guadiana). Over fishing of sea lamprey and habitat destruction resulting from dam construction, dredging, gravel extraction and channelization are the major threats to the conservation of Iberian lampreys. Conservation measures should guarantee maintenance of rivers longitudinal continuity and special pollution control of the rivers in which populations are still present, building fish passages in power stations and dams, limitation on dredging in river stretches used as spawning ground and ammocoetes beds, maintenance of water and sediments quality and adequate legislation regarding sea lamprey fishing.

11. Population size of the silver eel (*Anguilla anguilla*) population of the whole River Rhine catchment in 2004: a pilot mark-recapture study

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Over the last decades, the eel (*Anguilla anguilla*) shows a strong decline all over Europe. In order to protect the eel, the European Commission (EC) seeks scientific advice concerning targets for a.o. escapement of silver eels from catchments. In the meantime, the EC considers the possibilities of emergency measures, such as closing the fisheries. The Rhine is the largest river system in Western Europe and facilitates a large scale fishery on yellow and silver eel. Data on basic population parameters of the eel in this system, however, are rare. In 2004 a first attempt has been made to estimate the population size of the migrating silver eels > 50 cm of the whole River Rhine system. From August until November 2004, downstream migrating silver eels > 50 cm were caught in the

River Moselle (Germany), one of the main tributaries of the Rhine. 3,634 eels were marked on the ventral side with heliogenblue and subsequently released into the River Rhine at Koblenz, Bonn and Köln. Catches of silver eel from the 3 branches of the Rhine in the Netherlands (Waal, Lek/Nederrijn, IJssel) were checked for marks. Only 6 marked eels were found in the total batch of 6,200 eels. The population size estimate of the downstream migrating silver eels in the Rhine in 2004 (3.76 mln eels > 50 cm, biomass of 1.97 mln kg) probably is an over-estimation of the actual size of the population and should be quoted cautiously because a full synchronization of marking and recapturing efforts was not possible during the whole season.

12. Sea lampreys (*Petromyzon marinus*) upstream migration and the impact of dam destruction on catchment colonisation

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During the last decades, almost all the ecological studies conducted on sea lamprey (*Petromyzon marinus*) were undertaken in the Great Lakes region (North America) where this introduced species contributed to the decline of major fish stocks. The European perspective is in marked contrast to the experience in North America and European populations are considered as endangered mainly due to human activities (e.g. destruction of suitable habitats, pollution, land-management practices or river channelisation). The construction of dams is one of the major factors that have severely impacted anadromous lamprey populations. Barriers have been constructed in North America to eradicate or minimize sea lamprey populations by preventing adults to reach spawning areas. Nevertheless the effects of dam destruction on upstream migration of endangered population have never been investigated. From 1995 to 2002, the upstream migration of adult sea lampreys in the Scorff River (Brittany, France) has been studied using trapping and nest counting. In 2000 one of the river dams has been removed. In the present studies, we synthesise seven years of data on spawners migration and focus on colonisation processes in relation with water flow and dam destruction. After describing inter annual variability in spawners abundance, we focus on nest distribution along the catchment. Then, we evaluate the impact of dam destruction at a fine spatial and temporal level using data collected in 2002. First, our results show that despite the high variability in adult abundance among years and its relation with water flow, nest construction started by the lower part of the drainage. When the spawning area tended to be saturated, adults spawned in the next upstream suitable area. Second, dam destruction seemed to modify nests distribution along the river and to enhance the mean distance of nests to the sea, indicating an increase of the area available for juvenile growth

13. Study of statoliths of adult migrating lampreys (*Petromyzon marinus* and *Lamprolaima fluviatilis*) for the estimation of sea age

Dr Catherine Taverny, Françoise Daverat & Isabelle Ortusi

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Statoliths are calcareous aggregations localized in the labyrinth of the lamprey's inner ear. Analogous to otoliths in fish, they can allow the determination of age according to the watersheds. These calcified elements have already been used in the USA and Portugal to evaluate the age of *Petromyzon marinus* larvae, i.e. their freshwater age. A series of alternate translucent and opaque bands, reflection of a marked seasonal growth, is inscribed in the statolith. In the case of the Gironde Garonne Dordogne watershed, the freshwater age determination is realizable with statoliths of *Petromyzon marinus* and *Lamprolaima fluviatilis* larvae born in this watershed as well as with statoliths of adult migrating genitors of these species. Different hypotheses are made in order to give a sea age for these species, using genitors' statoliths. The first is to suppose that the increase in size of the statolith after the lamprey's metamorphosis follows the same evolution and is proportional to the time passed at sea. Second hypothesis : it is considered that no transformation of the calcium occurs concerning the statolith during the metamorphosis, period of physiological upheaval. This event is inscribed and can be identifiable in the statolith of an adult lamprey. The beginning of the validation of this hypothesis and is based on measures of the strontium/calcium ratio at given points on statoliths using microchemistry and is illustrated here.

Poster presentations:

“Life history strategies, tactics and adaptations”

1. Could variability in migration and reproduction strategies of Atlantic salmon be related to global climate changes?

Dr Edward Beall, Philippe Gaudin, Jacques Dumas, Alexandre Derrez & Iker Castege
INRA, Saint Pée sur Nivelle, FRANCE

2. The increase of female silver eels (*Anguilla anguilla*) proportion: a possible response to the general decline of the European eel recruitment

Dr Pascal Lafaille, Jérôme Guillouët, Anthony Acou, Anthoine Legault
Fish Pass, Chantepie, FRANCE

Temporal evolutions of European eels (elvers, yellow eels and silver eels) were examined over a 10-years period (densities, fluxes, size class structure, *etc.*) in the Frémur River (a 60 km² catchment in Brittany, France). Upstream and downstream migration fluxes were monitored daily using eel traps. Yellow eel stocks assessment was done yearly using electro fishing. Recruitment: From 2 000 to 25 000 eels colonized the river per year, that corresponding to an eel recruitment index from 40 to 500 eels.km⁻² (mean individual size: 135 mm). The total number of ascending eel was highest in 1998 and decreased rapidly from 1998 to 2003. Stocks: There is evidence that sex ratios, size and age at silvering are influenced by eel densities: male silver eels were more abundant in high densities and downstream area of catchment and females predominate in small densities and upstream area. However, the Frémur is a small river with high yellow eel densities in the whole catchment (mean density 0.5 eel.m⁻²). Fish passes were installed to conserve freshwater eel stocks and no significant decrease of yellow eel densities was showed, except in the most upstream area. Downstream migration: A total of 4 000 silver eels were caught and measured. The proportion of small silver eels < 450 mm (mostly males) decreased from 83% in 1996 to 60% in 2003. Inversely, proportion of large silver eels > 450 mm (females only) increased from 17% to 40%. In parallel, after an increased of silver eels from 1996 to 1999, the total number of eels in the downstream migration decreased rapidly since 1999. We noted the drastic decrease of the number of males, while the number of female silver eels remained stable on the same period. Conclusion: The European eel recruitment decreases throughout its distribution range. The consequences in the Frémur are (1) a rapid decrease of the downstream migration fluxes and (2) a change in the sex ratio of silver eels. Consequently, observed decrease of the silver eels stocks and gradual shift of silver eels sex ratio from male to female are a functional and rapid response to the general decrease of the eel recruitment. If this trend is general at the European eel distribution range, these consequences could be taking into account in the global management plan.

3. Dispersion and micro-habitat use in young shad larvae (*Alosa alosa* L.) under experimental conditions

Mr Philippe Jatteau & Agnès Bardonnnet
Cemagref, Cestas, FRANCE

4. Photoresponse of Allis shad (*Alosa alosa* L.) larvae: new insight into shad larvae behaviour

Mr Philippe Jatteau ,Thierry Rouault & Agnès Bardonnnet
Cemagref, Cestas, FRANCE

5. Aspects on the ecology of the sea lamprey (*Petromyzon marinus* L., 1758) larvae in Portugal: feeding, habitat selection, movement patterns, age and growth

Dr Pedro Raposo de Almeida, Bernardo R. Quintella & Nuno De Oliveira Andrade
Unidade de Biologia da Conservação, Universidade de Évora and Instituto de Oceanografia, Évora, PORTUGAL

6. Habitat selection by sea lamprey ammocoetes' age-classes: laboratorial assessment of their burrowing performance

Mr Bernardo Quintella, Nuno Andrade, Nuno Dias & Pedro R. Almeida
Instituto de Oceanografia, Lisboa, PORTUGAL

7. Silvering process and pressure resistance in the eel: metabolic aspect

Ms Aurélie Vettier, Philippe Sebert, Christine Moisan, Aline Amerand
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Eel is a particular fish species because it undergoes a reproduction migration (about 6000 km) during which environmental living conditions are very modified from river ecosystem (salinity, temperature, hydrostatic pressure (PH), oxygen, sustained swimming...). Before migration, eels metamorphose (silvering process). It seems that the different changes observed during this process prepare the fish to its new environment and activity pattern. In particular, there is an improvement of the aerobic capacities. The question raised in this work is to determine whether and how the silvering process contributes to pressure resistance. As migration represents a long swimming activity mainly performed with slow muscles, the red muscle energetics of pressure exposed silver eels was studied. After pressure acclimatization (101 ATA), no difference in cell metabolism was observed between silver and yellow eels (MO₂ is not affected, COX activity tends to increase but not significantly). However, if we relocate cellular energetics in an organismic context, pressure resistance could be evaluated by pressure threshold and maximal oxygen consumption at the end of compression (Table1, means \pm SEM). By comparing these results to what has already been shown in yellow eels, we point out that, concerning pressure resistance, the silvering process mimics the effects of pressure acclimatization in yellow eels (Table1). As pressure acclimatization is performed by the restoration of membrane fluidity (which is decreased by compression), we raise the hypothesis that the high-pressure resistance of silver eels is due to more fluid membranes. Pressure Threshold, bars MO₂, mmol/h/kg Silver eels 68 \pm 6 3,3 \pm 0,68; Yellow eels 42 \pm 2 4,9 \pm 0,35; Yellow eels 73 \pm 6 3,6 \pm 0,47; (acclimatized)

This study was supported by the EU project EELREP Q5RS-2001-01836

8. Elemental composition in otoliths of Japanese eels, *Anguilla japonica*: effects of ontogeny and habitat use

Dr Wann-Nian Tzeng, Chia-Hui Wang, Chen-Feng You, Mon-Dar Lee & Yoshi Iizuka
National Taiwan University, Taipei, TAIWAN

Trace element to calcium concentration ratios in the otoliths of silver stage Japanese eels, *Anguilla japonica* from southern Taiwan during their down stream migration were examined so as to understand their individual histories of migration between various habitats and the otolith elemental composition in relation to life stage and habitat shifts. Strontium to Ca ratios in the otoliths were analysed by electron probe micro-analyser (EPMA) and the ratios of 7 elements (Sr, Ba, Pb, Mg, Al, Na, and P) to Ca were measured by laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS). The temporal changes of Sr/Ca ratios in otoliths analysed by EPMA indicated that the migratory environmental history of the silver eels at the growth-phase, yellow eel stage could be divided into freshwater, seawater, and estuarine contingents that had similar marine leptocephalus life histories. Except for the Ba/Ca and Pb/Ca ratios, the otolith elements: Ca ratios of 5 other elements differed significantly among growth stages and habitat contingents. All of the 7 elements: Ca ratios differed significantly among the three habitat contingents. Ba/Ca and Sr/Ca ratios were negatively correlated to Al/Ca, Pb/Ca, and P/Ca ratios in the eel otoliths, indicating that individual elements were independently incorporated into the otolith. Canonical discriminant analyses indicated that approximately 68-90 % of the eels could be successfully assigned to different developmental stages and habitat use by their otolith elemental composition. This demonstrates that the trace elements in the eel otolith significantly changed with developmental stage and habitat and could be used as a tracer to reconstruct their life history trajectory and to monitor the environmental changes.

9. Migration between freshwater and estuary of juvenile American eels *Anguilla rostrata* as revealed by otolith microchemistry

Dr Brian Jessop, Yoshi Iizuka, Wann-Nian Tzeng, Jen-Chieh Shiao
Bedford Institute of Oceanography, Dartmouth, CANADA

The temporal patterns in the otolith Sr:Ca ratios of yellow-phase American eels *Anguilla rostrata* from the East River, Chester, on the Atlantic coast of Nova Scotia, indicated variable patterns of migration between river and estuarine/marine waters. Lengths-at-age and annual growth rates were higher for eels with a history of primarily estuarine residence than for eels of primarily freshwater residence. About 29% of yellow eels had a history of migration between river and estuary, with most (87%) making only one round trip. Longer eels tended to have an increased proportion of estuarine residency. The distribution within the river of yellow eels with a migratory history was clumped and tended to increase with distance upstream. The initial transition from estuary to river produced a check (false annulus) in 21% of yellow eel otoliths, as determined by the analysis of Sr:Ca ratio patterns. Otolith checks at intermediate ages not associated with a habitat transition occurred for 25% of yellow eels.

10. Salinity tolerance in young *Allis shad* larvae (*Alosa alosa* L.)

Dr Agnès Bardonnnet, Emmanuel Huchet, Frédéric Lange, Jacques Rives & Philippe Jatteau
INRA, St Pée sur Nivelle, FRANCE

11. Evolutionary Patterns in Six Microsatellite loci of Freshwater Eels

Dr Mei-Chen Tseng, Chaolun Allen Chen, Wann-Nian Tzeng, Sin-Che Lee
National Pingtung University of Technology & Science, Pingtung, TAIWAN

12. Genetic variation among brown trout migratory and resident phenotypes in the recent colonized hydrographic system of Kerguelen islands

Mr René Guyomard, Patrick Davaine & Katia Charles

INRA, Jouy en Josas, France

13. Partial migration of landlocked trout

Pr Ivan Olsson & Larry Greenberg

Karlstad University, Karlstadt, SWEDEN

14. Relationship between smoltification and maturity of sea trout, *Salmo trutta m.trutta* L., in a hatchery

Dr Piotr Debowski, Stefan Dobosz, Joanna Grudniewska, & Henryk Kuzminski

Inland Fishery Institute, Gdansk, POLAND

15. Histological comparison of the ovary development stage in farmed and wild European eels, and evolution of gonad development in hormone-treated fish

Mr Ignacio Jauralde, Luz Pérez, Daniel L. Garzón, David S. Peñaranda, Silvia Martínez-Llorens, Ana Tomás, Miguel Jover & Juan F. Asturiano

Universidad Politécnica de Valencia, Valencia, SPAIN

16. Interannual variability in the recruitment of young of the year of Allis shad in the Loire River

Dr Catherine Boisneau, Florentina Moatar, Mathieu Bodin & Philippe Boisneau

Université de Tours, Tours, FRANCE

17. Reproduction biology and ecology, and first larva's stages of the bouche-rondes *Sicyopterus lagocephalus* (Pallas 1770) and *Cotylopus acutipinnis* (Guichenot 1863) from La Reunion island

Mr Pierre Valade, Jean-François Ricou, Pierre Bosc, Henri Grondin & Puy Lim

Association Réunionnaise de Développement de l'Aquaculture, Etang Salé, FRANCE

18. Sea lamprey (*Petromyzon marinus*) spawning migration in Portuguese river basins studied by telemetry techniques

Mr Pedro Almeida, Bernardo Quintella, Nuno Andrade & Inês Póvoa

Universidade de Évora, Évora, PORTUGAL

The sea lamprey (*Petromyzon marinus* L.) is an anadromous species that uses some of the main Portuguese river basins to spawn. Sea lampreys are considered a gastronomic delicacy in Portugal, and due to the high economic value of this fishery (€ 30-45 per animal), the main Portuguese estuaries and rivers are crowded with fishermen and poachers during the annual spawning migration. Apart from intense fishing, habitat destruction as a consequence of dam construction is one of the major threats to the survival of this species. Mature sea lampreys begin their migration to the upper reaches of the Portuguese rivers in December. Peak spawning migration occurs between February and April and spawning usually takes place between May and June, depending on the meteorological conditions. This work gathers the main results obtained during the last six years studying the migratory behaviour of the sea lampreys, by means of several telemetry techniques (i.e. acoustic, radio and EMG telemetry), in Portuguese rivers. With the use of conventional telemetry techniques (i.e. acoustic and radio) it was possible to determine that during the upstream migration, sea lampreys presented a cruising ground speed of 16.5 BL min⁻¹. Increased river discharge at night, resulting from the operation of dams, stimulated lampreys' movements but reduced ground speeds recorded during periods of continuous tracking. Movements were more common during the night and dawn. The riffle areas created by the submerged blockstone weirs present in the river were used as preferential resting areas during the day. Electromyogram telemetry (EMG) was used to study the behaviour of this species through difficult passage areas. When swimming on stretches free from obstacles, the EMG values of lampreys showed a constant pattern of activity. Conversely, when negotiating difficult passage areas their behaviour were characterised by alternating between short bursts of intense activity (i.e. burst movements) and periods of motionless rest during which lampreys attached to convenient structures with their oral suckers. During blockstone weirs negotiation, tagged lampreys spent on average 23 % of the time swimming rapidly by means of multiple bouts of burst movements of 31 sec duration. To recover from each burst movement, the sea lampreys spent on average 2 min 25 sec resting. According to our results, sea lampreys seemed affected by increasing fatigue, which probably resulted from initiating a new burst movement without fully physiologically recover from the previous efforts. Telemetry techniques proved to be particularly useful to study the spawning migration of the sea lamprey, since it improved the knowledge on their ecology and behaviour and therefore gathered the necessary information to support the drawing of management and conservation proposals.

19. Silver eel migration pattern in the Baltic Sea

Mr Niklas Sjöberg, Erik Petersson & Håkan Wickström

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To evaluate the silver eels' migration pattern we have compiled data from all 268 different tag experiments carried out in the Baltic Sea since the first one took place in 1903. One-third out of these have been put together in a database containing individual information of about 5,000 recaptured eels. The migrated distances from the release locality to the place of recapture were calculated using a navigation program. The migrated directions were classified as „Sexpected“T or „Snot expected“T. To separate the different migration routes passing Denmark and Öresund that area was divided into different zones. The results showed that: (1) The proportion of recaptured eels declined from 1959 to 1991. (2) The number of „S Shibernators“T increased with the latitude of the release locality. (3) The migration distance and the proportion of eels that reached the Öresund area and the Danish straits increased with the longitude of the release location. (4) The proportion of eels with a „Snot expected“T migration direction increased with the longitude but declined with the latitude of the release location. The Swedish eel fishery is partly based on re-stocked eels, which are either translocated domestic yellow eels or imported elvers. The aims of the stockings are to contribute both to the fishery and to the spawning stock in the Sargasso Sea. However, it is hypothesized that the stocked eels (as opposed to natural ones) do not find their way out of the Baltic and this could be because of the lack of imprinting and thereby re-stocked eels lack the orientation mechanism necessary to locate the outlet. The statistical calculations of the Swedish tagging experiments show a displacement in emigration direction over time, from the Öresund area to the Danish straits. However, this turnover took place before 1975, i.e. before any large-scale stocking program had started in Sweden. In addition, tagged Polish eels have been recaptured as far north in the Baltic as north of the island of Öland. These findings

suggest that a portion of the eels tagged in the Swedish experiments were not naturally immigrated, but were previously stocked in Poland or East Germany. Therefore, we suspect that the large-scale stocking programs that started in Poland and East Germany in the 1950s are likely to have influenced the Swedish tag experiments since then.

Poster presentations:

“Human activities and Diadromous fish”

1. An original eco-anthropological approach to identify a diadromous species that could materialise the recovery of the water and habitat quality within the Seine basin

Dr Patricia Pellegrini, Mélanie Béguer, Julie Marchal, Jean-Luc Baglinière, Dominique Ombredane & Eric Rochard

National Museum of Natural History, Paris, FRANCE

2. Establishment of a eel board within the river catchment Rhone-Mediterranean-Corsica: the case study of a glass eel monitoring recruitment to a lagoon system within the Rhone delta

Mr Nicolas Auphan, Alain Crivelli, Marc Barral & Jean-Yves Menella

Association Migrateurs Rhone Méditerranée, Arles, FRANCE

European eel is threatened at a National and European scale and there is a need to establish eel board with the aim to manage and monitor this species in all French river catchments, including that one called Rhône- Mediterranean-Corsica. A first study has been undertaken to summarize all available data within the study area. This work included qualitative as well as quantitative data on the three ecophases of eel and on its fishery. The conclusions have been that there was a lack of suitable data and gaps for biological data on this species needed for a comprehensive and efficient management as well as no reliable fishery statistics, and a lack of implementation of the existing legislation. For example, data on glasseel are totally lacking, and there is no fishery statistics on this life stage because such a fishery is forbidden in the Mediterranean French part. In the contrary, there are quite a lot of data on yellow eel, however, those are not always very useful and helpful to draw suggestions for management. Finally, there are no data on migratory silver eel stage within the whole studied catchment. To improve the situation, a first study has been undertaken on potential favourable sites within the river catchment to monitor glasseel recruitment using glasseel traps, and then to be included in the European network so-called "Glasseel Monitoring". 32 lagoons and 28 coastal rivers have been investigated. A set of criteria has been set and examined on each site, and finally eight sites have been selected as potential sites to install such a glasseel trap system. Among those 8, only five were kept. In autumn 2003, the first one, the "grau de la Fourcade" located within the river Rhône delta was equipped with a glasseel trap made by the company FishPass. The trap has been effectively working since January 2004. From January to December 2004, the trap was visited 120 times and 1,378,399 glasseel have been caught. Half of them were caught in the peak month, February. The majority of those glasseel have been marked with tetracycline and released with the lagoon system of the Rhône delta. This marked cohort will be monitored up to the silver stage within the framework of a long-term study on the population dynamics of eel within the lagoon system of the Rhône delta (Project leader: A.J. Crivelli). This study will continue in 2005 and 2006 using the same procedure.

3. Assessment of yellow European eels populations trends: toward the establishment of a common methodology?

Mr Emilien Lasne, Pascal Laffaille & Christian Rigaud

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Providing reliable and regular evaluations of diadromous populations' trends in continental waters (in terms of abundance and recruitment) is crucial in a management perspective, but it still remains a hard work. Sampling and analytic methods should be developed to provide evaluation of catchments populations' general trends (temporal analysis) and standardized data that permit comparisons between catchments or sub-catchments. In addition, costs of survey should be as low as possible. The salmon index, based on the sampling of juveniles in headwaters, is a good example of such methods with their concrete applications. In spite of the drastic decline of the European eel throughout its distribution area, there is a lack of standardized methods for its survey within the different catchments it colonizes. In this communication: 1. we review the main reasons of this lack and the different information we may look for, 2. we argue for new complementary procedures based on the spatio-temporal survey of the smallest (<300 mm, mainly 0+ to 4 years individuals) yellow eels. Indeed, this favoured observation can better inform on the recent recruitment level of a given catchment (or sub-catchment) than the survey of all the size classes present within these areas. Moreover, when they are present in a given compartment of a catchment, they colonize the shallow waters (riffles, floodplain waterbodies) we can effectively sample by electrofishing. Then, different authors suggest that colonization processes are mainly density-dependent and that increasing downstream densities lead to more intensive upstream migrations. If such hypothesis is confirmed, spatio-temporal patterns of distributions of the small eels all along of a river within a catchment (for example maximal distance from tidal limit) would inform on downstream occupancy fluctuations (more or less linked to the glass-eel input in the estuary and to yellow eels densities already present in the systems) and on the permeability of river for eels migrations. 3. We present the first attempts of these small eels surveys within small streams (e.g. Brittany streams) and large rivers (e.g. Loire River). Finally, we discuss about the possible development of a Scolonization index and its applications in a management perspective.

4. Modelling the spatiotemporal variations of eels abundance in small catchments: interest for eel stock assessment

Mr Anthony Acou, Etienne Rivot, Pascal Laffaille & Eric Feunteun

Université de Rennes 1, Rennes, France

Investigating the factors which influence the temporal and spatial variation of fish abundance is of prime importance for the development of models aimed at predicting the abundance of populations in different ecosystems. Spatial distribution of catadromous eels (*Anguilla anguilla*, L.) in watersheds is strongly influenced by upstream migrations that depend upon dynamic and directional processes from the estuaries. It is also influenced by some interactions between size-dependant swimming/climbing abilities and river characteristics (e.g. size, spatial continuum integrity and habitat) that control migration patterns (e.g. speed, distance covered). Therefore, the distance to the sea (macroscale parameter) is a key factor that usually controlling both abundance and average size of European eels in large river system. At a lower spatial scale, most studies have failed to clearly determine habitat preferenda (microscale parameter) illustrating the opportunistic characteristics of this species. The aim of the present paper is to investigate the spatiotemporal variations of eel abundances at the scale of a small dammed river system in western France, the Frémur R. The sub-population was quantitatively sampled for seven consecutive years via electrofishing. In such a river, the recruits of a single cohort may colonize the whole system in a single upstream migration. Therefore, the spatial variation of the abundance is likely to depend upon the availability of the suitable habitats that may be reduced by (i) river development limiting the river continuum and (ii) high biotic interactions as density dependent competition. We used a Generalized Linear Model to analyse the spatial and temporal variations of eels abundance. The statistical analysis enables us to simultaneously introduce the influence of different factors, such as the years (temporal effect), macroscale parameter (i.e. compartment localisation defined by both downstream and upstream obstructions) and habitat characteristics (habitat profile, substratum and vegetation cover). The analysis revealed that different models must be constructed for the different size classes and stages of eels, thus revealing that the temporal and spatial variations of abundance depends upon size classes. The results and potential extrapolations of the models for stock assessment at the whole catchment scale are briefly discussed.

5. Environmental factors influencing the immigration of the catadromous European Eel *Anguilla anguilla* L. to the Lower River Shannon, Ireland

Dr T.K. McCarthy & William O'Connor

National University of Ireland, Galway, IRELAND

The European eel is a fish of significant ecological and commercial importance. Because of its extensive migrations and longevity, it is a unique indicator of the health, integrity and connectivity of our oceans, estuaries and freshwaters. The River Shannon (catchment area 11,700 Km²; mean annual discharge 176m³sec⁻¹) is the largest river in the British Isles. Hydro-electrification of the river in its lower reaches during the 1920's significantly reduced natural recruitment of eel to the catchment, and this has been mitigated since 1959 with a trapping and overland transport programme. Although this endeavor was initially effective, the numbers of eels trapped has progressively declined from the early 1980's onwards, in line with the international decline of this species. In the current study, available historical information on juvenile eel trapping on the river is reviewed and an intensive five year investigation, involving netting and trapping assessments in both estuarine and riverine areas, is reported. A total of approximately 18.6 million immigrating juvenile eels were intercepted during the assessment. The results suggest that environmental factors such water temperature, tidal currents and to a lesser extent factors such as wind influence the activity of glass eels in the water column during the estuarine passive migration stage. Some glass eel activity was recorded in the estuarine water column at temperatures as low as 3-4oC. The main environmental factor controlling riverine migration was water temperature and the onset of active migration coincided with spring tides and a threshold water temperature of 10-12oC. The end of the main migratory activity was not found to be temperature related and may be subject to seasonal influences. Both estuarine and riverine migrations were found to exhibit a diel periodicity, with greatest eel activity recorded during dusk and the early hours of darkness. River flows were found to exert a strong control on the success of eel ascent into freshwater areas, and the potential of manipulating flows on regulating rivers to improve eel immigration success is examined.

6. Diadromous species in French inland waters: comparisons and evolution of re-stored data series (1978-2002) and of recent landings and fishing efforts (1999-2002)

Dr Gérard Castelnaud, Thomas Changeux, Alde Grandpierre & Laurent Beaulaton

Cemagref, Cestas, France

7. Long term and seasonal variation in rod and net catches in a large subarctic salmon river

Dr Eero Niemelä, Jaakko Erkinaro, Sturla Brörs, Brian Dempson, Markku Julkunen, Panu Orell, Martin Svenning, Maija Länsman & Esa Hassinen

Finnish Game and Fisheries Research Institute, Oulu, FINLAND

In the Ebro Delta, one of the main sites for glass eel recruitment in Western Mediterranean Sea, European glass eels (*Anguilla anguilla*) are captured when they migrate from marine to freshwater environments by means of a traditional fishing device locally named as "bussó". Glass eel fishery in the area of this study is restricted by the Administration from October to March. Glass eel capture and manipulation is performed by fishermen using methods during which not a great deal of care is taken in relation to glass eel health, and even less to other species captured with the fishing gear, normally gray mullets, which generally have no commercial value. Fishing procedures, which normally do not affect the glass eel, have a great impact on the health and survival of the accompanying ichthyofauna, affecting the natural recruitment of these species. However, up to know any study

has been conducted to evaluate the impact of these procedures on the survival of recruited species. We measured the above-mentioned impact by recording glass eel captures in three sampling stations distributed in the Ebro Delta at the river and drainage channels connecting the inner land (rice fields) with the sea. Different authorized professional fishermen managed each sampling station, allowing the evaluation of different fish handling and selection procedures. In each sampling station, the following parameters were recorded: captured glass eel and accompanying ichthyofauna individual number and biomass, species measurement and identification, mortality of accompanying species derived from fishing engine handling and glass eel handmade selection. As the capture and selection of glass eels is a stressing procedure for accompanying fish species, we evaluated its effects on the short-term mortality of fry by stocking them in open-flow freshwater tanks during five days, during which period mortality was recorded regularly. At the end of the stocking period, live fish were counted, identified and measured and returned to their respective capture point. Preliminary results indicated that glass eel capture, selection and handling have negative effects on the survival of the ichthyofauna captured with glass eel fishing device. The fishermen trap the eels and fish in a rigid mesh and then with diagonal hand movements strongly agitate and push the eels and fish against the mesh (3-5 mm inner diameter). This repeated action causes the eels to pass through the mesh while the fish remain caught above. This process causes abrasions and de-scaling of the fish (grey mullets mainly) that often turn into bacterial and fungal infections. Recorded data showed that skin lesions affect the ca. 50-90% body surface. During glass eel selection and handling, all fish are kept out of the water during five to ten minutes, which may cause severe problems of hypoxia in accompanying fish, but to a lesser extent to glass eels (skin mucous protection and cutaneous respiration). Results regarding the incidence and list of accompanying ichthyofauna, as well as their mortality associated with glass eel capture, handling and fish selection are presented in the current study. Recommendations regarding the improvement of glass eels capture, handling and selection procedures are also showed and we expect to test them during the second year of the project.

This study was funded by 2004ACOM-0047 by Generalitat de Catalunya (Spain).

8. The reconstruction of an Atlantic salmon population in the Belgian River Meuse basin

Dr Jean Claude Philippart, Michael Ovidio, Vincent Frank, Colette Conjearts, Pierre Gerard, Alain Gillet & Jean Claude Micha
University of Liège, Tihange, BELGIUM

9. Conservation of Atlantic salmon: new biological data are required to improve restocking in large European rivers. The example of the Loire

Mr Patrick Martin, Lucien Jonard , Jocelyn Rancon , Eric Verspoor , Jack Falcon , Gilles Boeuf & Sylvie Dufour
Fondation Saumon, Chanteuges, FRANCE

10. Etablissement d'un stock ex-situ de l'esturgeon européen *Acipenser sturio* en danger critique de disparition : Gestion des données

Mr Vincent Bouju, Thierry Rouault, Patrick Williot & Jacques Massé
Cemagref, Cestas, FRANCE

11. Sturgeon in Sweden - past, present and future

Dr Susanna Pakkasmaa, Torbjörn Järvi, Erik Petersson & Jonas Pettersson
National Board of Fisheries, Drottningholm, SWEDEN

12. Discrimination between restocked and naturally recruited European eels *Anguilla anguilla* by otolith Sr:Ca ratio analysis

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Glass eels *Anguilla anguilla* collected from the UK and France have been restocked in Lithuanian waters and mixed with naturally recruited eels for several decades. To distinguish the restocked eels from naturally recruited ones and to understand the migratory environmental history of the eel, strontium (Sr) and calcium (Ca) contents in otolith of the eel were examined using an electron probe microanalyzer equipped with wavelength dispersive X-ray spectrometry. The eels were sampled from the brackish Baltic Sea and a freshwater lagoon and lake in Lithuania. Restocked eels released as glass eels in freshwaters can be identified by a low Sr:Ca ratios freshwater signature on the otolith after glass eel stage. Naturally-recruited eels, that had migrated from the Atlantic Ocean, through North Sea and Baltic Sea, were characterized by an extended high Sr:Ca ratios seawater signature after glass eel stage. Of 108 yellow and silver eels analyzed, 21 eels had Sr:Ca ratio profiles consistent with restocking while 87 showed the patterns of natural recruitment. The eels collected from Lake Baluožai were all restocked origin; however, the restocked eels accounted only 20% of the eels in the Curonian Lagoon and 2% in the Baltic coast. This finding does not support the hypothesis that eel fishery in the Curonian Lagoon mostly depends on restocking. The eels from the lagoon and Baltic Sea showed varied migratory histories between fresh and sea/brackish waters, either seasonally or irregularly. Migratory eels (70%) outnumbered both freshwater- (6%) and seawater-resident eels (24%). Naturally recruited eels invaded Lithuanian freshwaters at a mean age of about 4 - 5 years (range 1 - 10 yrs), which was much older than those recruited to the Atlantic coastal countries. The eel migration from Atlantic Ocean to southeastern Baltic Sea is a highly flexible and complicated process.

13. Polycontamination of Eels in the Gironde estuary (Metals and Organic pollutants)

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The Gironde estuary shows a large fish assemblage (75 species), among them, the European eel. This species declines in all Europe as well in the Gironde estuary. Concurrently to this decline, biomonitoring studies using shellfish and fish have shown high metal pollution levels (especially for Cadmium) and a relatively high level of Persistent Organic Pollutant (especially for Polychlorobiphenyls PCB) in the Gironde estuary. In order to investigate the level of contamination and its impact on eel's population dynamics, metals (cadmium, copper, zinc and mercury) and organic pollutants (PCB) were analysed in correlation with biological parameters such as age, growth, degree of maturation, and habitat use based on Sr/Ca ratio. In May and September 2001, eels were sampled in Gironde estuary and were dissected for metals analysis (gills, liver, muscle and kidney), for organic analysis (muscle and liver), and for life history and age determination (otoliths). Studied eels presented relatively homogeneous characteristics (9.5 ± 2.2 years; 63 ± 16.5 cm length and 530 ± 152 g weight) and display significant estuarine residence time (at least 4 years). Metals analysis results showed significant differences between the four organs, and between the four metals. Even though metal concentrations measured in fish muscle and gills are low in general, ([Cd_{muscle}]: 0.03±0.01 µg.g⁻¹, dw, [Cd_{gills}]: 0.80±0.11 µg.g⁻¹, dw), high levels of cadmium, zinc and copper were observed in kidney and liver ([Cd_{liver}]: 4.98±0.8 µg.g⁻¹, dw, [Cd_{kidney}]: 34.19±5.14 µg.g⁻¹, dw). The organic analysis results, show globally high levels of PCB, particularly in muscle (about 1000 ng/g dry weight for the 7 PCB classified as priority indicators CB 28, 52, 101, 118, 138, 153, 180).

This level of contamination could raise sanitary problem, on the basis of the recommended daily input for the seven prior PCB given by the AFSSA (Agence française de sécurité sanitaire des aliments). The difference in level of contamination cannot be explained by the time spent in the estuary. However, contamination could be related to growth rate, to habitat use and diet.

14. Impacts of the Belver dam on the European eel, *Anguilla anguilla* (L., 1758), population (River Tagus, Portugal)

Dr José Lino Costa, Eric Feunteun, Carlos Assis, Pedro Raposo Almeida, Francisco Moreira, Isabel Domingos, Maria José Costa

Universidade de Lisboa, Faculdade de Ciências, Lisbon, Portugal

Samples of the European eel, *Anguilla anguilla*, collected both in the upper estuary and near the Belver Dam, 200 km upstream from the river mouth, were used in order to investigate the effects of this barrier on the abundance, condition factor and sex ratio of the Tagus' eel population. The drastic reduction of this species distribution area in the Tagus basin caused by the presence of the Belver dam led to an increase in eel density below the obstacle and induced the occurrence of low condition individuals. This forced concentration of specimens has also resulted in an artificial manipulation of sex ratio, favouring males. The low condition of the individuals and the reduction of spawning biomass contribute to menace the species' reproductive success and its economic potential. Some suggestions to prevent the described constraint and preserve the European eel as a resource in the Tagus River are also presented.

15. Influence of a siphon on the upstream migration of fish on the Kleine nete, Belgium

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The disruption of longitudinal connectivity by man-made obstacles threaten the fish fauna of Belgian rivers to various extents. Access to the spawning areas and habitat loss are at present the main bottlenecks in the life cycle of these species. All this resulted in the drastic range reduction or the extinction of numerous migratory fish species. However, the impact of some potential obstacles to fish migration into the spawning tributaries remains poorly documented. The Kleine Nete is a small river in the north-eastern part of Belgium. In the past there were many interventions at the Kleine Nete in behalf of agriculture and flood control. Different weirs now regulate the water level. About 30 fish species are found in the Kleine Nete, including a few diadromous species: European eel (*Anguilla anguilla*), flounder (*Platichthys flesus*) and European brook lamprey (*Lampetra planeri*). In the autumn of 2004 the possibility for fish to pass a siphon was investigated. This siphon is the first potential obstacle for free migration of catadromous fish species heading the Nete basin and coming from the North Sea. Upstream, a three-km long river stretch links the siphon to a weir. The capacity of passage through the siphon was measured through a PIT-tag field survey. PIT-tagged fish were translocated from upstream (siphon till weir) to downstream of the siphon. In this manner we tried to trigger the fish to swim upstream through the siphon. Daily sampling has proven the capacity of migrating through the siphon of 10 individuals of 9 species. Only very few diadromous species were captured during this sampling period and for these species no migration through the siphon could be established. A general discussion of these results focuses on migration through the siphon and possible interfering with it.

16. Connectivity and habitat restoration in rivers helps populations of salmonids?

Dr Hans Lundqvist, Peter Rivinoja, Kjell Leonardsson, Johan Östergren, Jaan Kiviloog, Lars Bergdahl, Skip McKinnell & Lars Brydsten

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17. Programme de restauration des voies de migration de l'Alose sur la Vilaine au XIX siècle

Mr Antoine LEGAULT & Jean René CADIOU

Fish Pass, Chantepie, France

18. Natural-like fishways for re-establishing connectivity

Mr Olle Calles & Larry Greenberg

Karlstad University, Karlstad, Sweden

We evaluated the function of two natural-like fish ways for re-establishing connectivity for anadromous salmonids in the regulated River Emån. Between 90-100% of the salmonids that entered the fish ways actually passed through them, with median speeds of 180-190 m h⁻¹. Only 50% of the anadromous brown trout that passed the first fish way also passed the second one, indicating that the fish might have had problems locating the upstream fish way. The fish ways were also observed to function as a passage for downstream post-spawning migrants. The densities of brown trout yearlings upstream of the fish ways were higher in 2002, after the fish ways were built, than during pre fish way years. In control sites in other parts of the river as well as in a nearby river, no changes in yearling densities were observed. Thus, the fish ways are working for upstream spawners, albeit at a recolonization rate that is slower than expected.

19. Making in-river structures passable for migratory fish

Ms Josee Peress

Environment Agency, Exminster, UNITED KINGDOM

The objectives of the presentation are to show how the Environment Agency makes in-river structures passable for migratory fish when designing, constructing and operating flood alleviation schemes and river flow gauging weirs. Flood alleviation schemes and river flow gauging weirs can create obstructions to fish passage by reducing significantly the time period of accessibility through the scheme, by excluding fish from key areas necessary to complete the migratory fish's life cycle, or by causing losses of fish. The range of structures includes tidal flaps (often at the entrance to a river), culverts, over widened channels, storage areas and crump weirs. When designing and constructing flood alleviation schemes and river flow gauging weirs the Environment Agency integrates into the design of the scheme criteria ensuring fish passage, without compromising the primary function of the structure. The design criteria take into account fish biology and physical capability of fish. Such biological factors are then related to hydraulic conditions, ensuring that such conditions are suitable for fish over the relevant flow range. Example of a flat vee gauging weir at Gribbleford (River Lew, Torridge catchment, Devon, SW England): The scheme entails replacing a gauging weir (low-level bed control) by a flat vee to provide more accurate river flow measurement. The site is situated in a migratory salmonid river at the head of the catchment. Suitable spawning habitat is located above and below the site. The challenge is to minimise obstruction to fish passage. Hydraulic modelling was carried out on the outline proposal so that design criteria for fish movement are met for the relevant range of flows. The range of flows is determined according to the period of migration and acceptable risk. Example of flood alleviation scheme at Habertonford (River Harbourne, Dart catchment, Devon, SW England): Scheme entails an online storage area, retained by a dam through which a section of the river is culverted. The site is situated in a migratory salmonid river. To minimise the obstruction to fish passage, a minimum depth of water was maintained in the culvert through the creation of a pool at the entrance of the culvert. Heterogeneous water velocities were created using a gravel bed throughout the culvert.

Influence of a siphon on the upstream migration of fish on the River Kleine Nete in Belgium

H. Verbiest, C. Geeraerts, C. Belpaire

The River Kleine Nete

The River Kleine Nete is a small river in the eastern part of Belgium (Fig. 1). It belongs to the River Scheldt basin. It is 50 km long with a drainage area of 815 km². Up to the weir in Grobbendonk it is a tidal river with luxuriant vegetation (Fig. 2). About 30 fish species were found. Some of them are rare species in Flanders like spined loach (*Cobitis taenia*, L.), weatherfish (*Misgurnus fossilis*, L.), bullhead (*Cottus gobio*, L.), dace (*Leuciscus leuciscus*, L.) and European brook lamprey (*Lampetra planeri*, L.).



Fig. 3: Location of the barriers on the River Kleine Nete

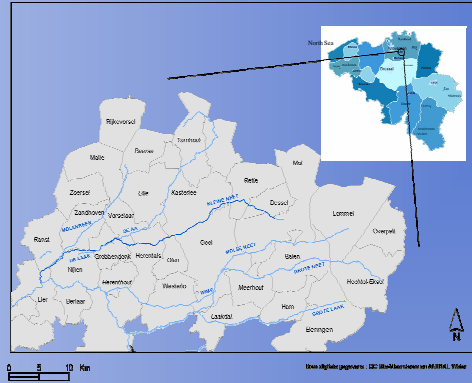


Fig. 1: Location of the River Kleine Nete in Belgium

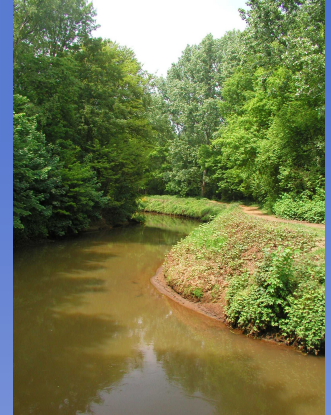


Fig. 2: The River Kleine Nete

Obstacles

The river has been regulated to ensure water control and to improve agricultural purposes. Actually several weirs regulate the water level and two canal siphons were built (Fig. 3). A siphon is a culvert that brings water courses under a canal which means that it is not completely straight but it has two or more kinks. The first potential obstacle in the River Kleine Nete for free migration of diadromous fish coming from the North Sea is the siphon under the Nete canal. The second potential barrier is the siphon under the Albert canal (Fig. 4).

Methods

The aim of the study is to assess the mobility (migration/movement) of fish through the two successive siphons on the River Kleine Nete (Lier-Grobbendonk). For this reason different sites were sampled during 2004. Fish assemblage data were sampled by electric fishing every two weeks (Fig. 4). All fish were fin clipped. Data gave an overview of the presence of eel (*Anguilla anguilla*, L.), lamprey and flounder (*Platichthys flesus*, L.) in this river. A more detailed survey was done in autumn 2004 using PIT-tags (Fig. 5). Upstream PIT-tagged fish were translocated downstream the siphon. To ensure a successful recapture, fyke nets were used to close up the river upstream and downstream the siphon.

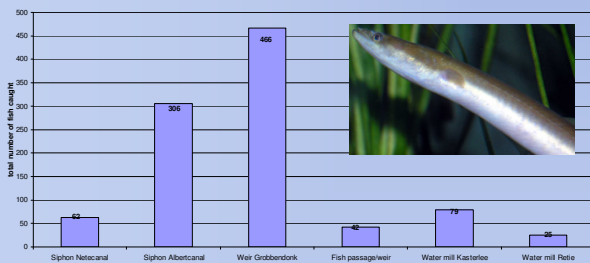


Fig. 7: The influence of obstacles on the distribution of eel on the River Kleine Nete

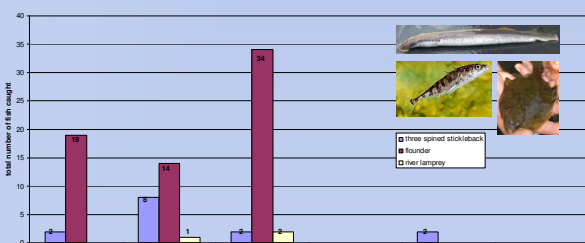


Fig. 6: The influence of obstacles on the distribution of three spined stickleback, flounder and lamprey on the River Kleine Nete

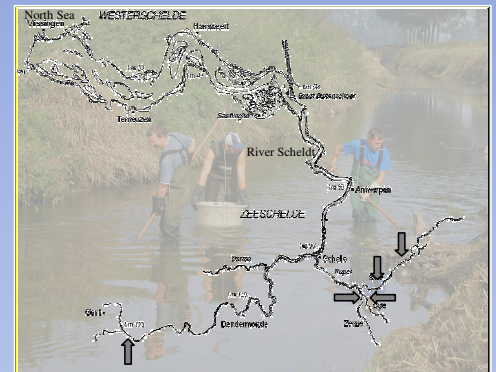


Fig. 4: Potential barriers for diadromous fish coming from the North Sea and electric fishing in the Kleine Nete



Fig. 5: PIT-tag

Results and conclusions

Both experiments have proven migration through the siphons of 38 individuals of 8 freshwater species (perch (*Perca fluviatilis*, L.), roach (*Rutilus rutilus*, L.), gibel carp (*Carassius carassius aurelio*, L.), chub (*Leuciscus cephalus*, L.), tench (*Tinca tinca*, L.), gudgeon (*Gobio gobio*, L.), rudd (*Scardinius erythrophthalmus*, L.) and stone loach (*Barbatula barbatula*, L.). Unfortunately, it was impossible to gain an idea of the part of the population able to migrate through the siphons. Only very few diadromous species (eel, flounder and lamprey) were captured during the sampling period. For flounder and lamprey migration through the siphons could be confirmed as they appear at the weir in Grobbendonk, upstream the two siphons (Fig. 6). This shows that at least a few individuals are able to pass these siphons. It's difficult to determine the migration pattern of eel because it is abundantly restocked and is able to climb up the wall near the weir. Two causes of its wide distribution over the whole river (Fig. 7). This leads us to conclude that fish can migrate through the siphons investigated on the River Kleine Nete, but it is unknown which part of the populations is able to pass.

