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1 Executive summary

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2 Introduction

2.1 Purpose of the report

This paper reports the goals, rationales, model hypothesis and results of the developments carried out at the EEA to assess the impact on river fragmentation by obstacles *vs*. fish. Two other separate reports address respectively sediment budget issues and hydrological fragmentation.

The three reports share comparable introduction to preserve coherence, the issues specific to each aspect being restricted to the specific report.

2.2 General issues of river systems fragmentation

River systems are naturally more or less free flowing channels in which the upstream – downstream circulation of water, sediment and biota and the downstream – upstream circulation of biota are driven by natural regime, the presence of lakes, cascades and the characteristics of floodplains that are circulation corridors for terrestrial fauna.

Most European river systems have been modified by human action for long ago: cities, dams, locks, weirs, dykes, abstractions and derivations, pollution discharge, etc. They are more and more related together by canals and aqueducts. At the end, the systems are both more fragmented into sub-systems in which the original possibilities of circulation are restricted and at the same time more and more connected, allowing alien species to colonise new areas, along with the wilful introduction of species.

The term “fragmentation” applied to rivers is defined by UNEP as *“the interruption of a river's natural flow by dams, inter-basin transfers or water withdrawal”* [1]. This definition restricts the application of the term to human action and practically refers to transversal fragmentation applied to hydraulics.

The UNEP definition is quite restrictive when considering the possible impacts: it focuses only on transversal obstacles installed by humans. Many rivers are as well fitted with *longitudinal obstacles* (dykes, encroachments, etc.) that change the possibilities of exchanges of water, sediment and biota between the river bed and its flood plain. The effects of this longitudinal fragmentation are not considered in this report.

Water quality is a well a potential obstacle since long reaches of bad quality or salinity out of the acceptable ranges act as effective barriers to fish migration.

To better capture river fragmentation as it impacts the natural conditions of river ecosystems and modifies (without positive or negative judgement) the services they provide, the concept of “obstacle” was introduced to widen the definition of fragmentation. For example, cascades and natural lakes naturally fragment the system. They should ideally be considered since the assessment of the human share of river fragmentation assessment would be biased otherwise.

In a first stage of development presented in this report, only dams are considered as obstacles. The reason is the lack of available data and suitable methodology along with the likelihood of limited impact from natural obstacles in the areas where the calculations were planned to be carried out. The principles of considering other types of obstacles are discussed, but the application is limited to the effect of damming.

Connectivity issues are not considered either, even though they might mitigate fragmentation effects in some sub-basins and adversely trigger dissemination by alien invasive species in many cases, thus reinforcing the adverse effect of fragmentation on indigenous species.

Addressing fragmentation, in the wide acceptation indicated above, is obviously depending on the mutual relationship between the physical size of obstacles, the type and the characteristics of targets and the timescale of phenomena. There is no simple rule that could be applied to separate what obstacle matters from what is insignificant. This is expected to be the result of a compromise between expertise,

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[1] http://www.unep.org/vitalwater/23.htm, checked 8/01/2007.

validation and assessment. This is however an important issue because its answer drives the data collection effort.

Literature analysis suggested however that the fragmentation issues must be addressed at the system level, considering explicitly the combined effect of series of obstacles even though each one has potentially a limited impact. A second outcome from literature is that the order of obstacle implementation is a major issue in understanding the behaviour of natural systems; hence the historical aspects of obstacle developments are carefully considered.

2.3 Context of the calculation module development

The EEA launched the development of a calculation module as part of the spatial platform to compute different indicators of river fragmentation. This report presents the objectives, rationales, hypothesis and indicators produced by this module focusing on fish considered from the migratory and residence perspectives.

River systems in Europe have been modified by human action for centuries. These modifications are the counterpart of the storage of water resource, hydropower production, protection against flood, recreation, etc. that result from hydraulic management.

The major issues related to the presence of natural and artificial obstacles, physical and chemical are:

- Substantial changes in the water cycle, water being stored and diverted, the hydrologic regime is modified at the scale of few minutes to decades.
- Substantial changes in the sediment and nutriment transfer to the sea, because of sediment trapping and neo-formation of sediment in lakes (including artificial reservoirs)[2] and possible release in shorter times, the correlative impact being the clogging of reservoir capacity by sediment trapped in the impoundment,
- Substantial change in the travelling possibilities of fauna and flora, with differentiated impacts considering the amphibiotic fishes, the resident fish populations and the transfers of seeds and propagules[3] along water courses. The correlative impact is the transforming of free-flowing river stretch into a slow flowing one. Hence passing is not enough to avoid impact is fish cannot find suitable habitats upstream the passed obstacle.

Several works have been carried out to define, analyse and report fragmentation by large dams (Nilsson, Reidy *et al.*, 2005). This work aims at implementing relevant indicators production within the framework of environmental accounting (SEEA), considering both sides of the issue: economic and environmental impacts.

To this end, the data structure needed to achieve the fragmentation indicators is embedded in the “spatial platform” under development, as part of the EEA data infrastructure. It uses the river GIS, the Eldred2 database on dams and adequate inputs from ETC/LUSI, ETC/BD and ETC/W.

Many progresses make it possible to carry out this work now.

1. Different developments, of which the progressive integration of the national river GIS to achieve a calculable River & Catchments database (ERC2[4]) which components are adequately connected, routed and to which objects can be snapped without error. This database development is on going, with sample basins already carried out for model benchmarking,
2. The development of Eldred2, a well documented and populated database on large dams which position is known. This database is completed by information on all dams in some catchments, making it possible to analyse the possible bias in indicators,

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[2] This phenomenon, related to calcium precipitation is well known for long ago.

[3] A propagule is any part of an organism that can be detached from the organism and disseminated in hopes of it growing in a new environment. In this report, “propagule” deals with plants only.

[4] ERC2 comes from ERC (European Rivers and Catchments) built from CCM2 catchments and EGM (Euroglobal map) and ERM (EuroRegional map)rivers supplemented by the adequate topology and routing carried out by the ETC/LUSI.

3. The delineation of the largest (>25ha) lakes was carried out using CORINE *land cover* and the merging with other data sources,
4. A conceptual model and data model merging these different sets made it possible to define (and stepwise implement) the operational links between these elements, in close relationship with the development of the WISE GIS works,
5. The definition of suitable descriptors and derived indicators, including proxy values when any of the components is lacking and prevent carrying out the normal process of calculation.

The conceptual backgrounds of systems fragmentation come from the researches published by several authors, institutions and global projects, with special mention to the GWSP project[5], with which close relationships are established on the one hand and, at detailed level regarding fish issues the Cemagref and the Loire basin authorities (EPL and ONEMA[6]) involved in restoration of salmon and eel on the Loire river and its tributaries.

2.4 Report contents

This report describes the targets, rationales and implementation of the calculation module implemented in the spatial platform (SPAICE) under NOPOLU *Système 2* to compute fragmentation data and indicators.

In a first stage, the module is calibrated on the French Loire river catchments. Its implementing and calibrating on other European basins is depending on the development of the calculable ERC2 river GIS and on the availability of positioned dams and supplementary documentation about their relevant characteristics.

The module capabilities have been designed in a flexible way to account for the very diverse quality of GIS and data that may be expected from different areas. This posed several problems of descriptor and indicator consistency and accuracy that are discussed in the report.

A major expectation from the calibration and validation steps is precisely to address the bias, errors and uncertainty resulting of different levels of data availability.

It comprises a first section where the rationales of the fragmentation by obstacles vs. fish issue are presented and which simplifications are considered. A second section presents the comparison of results from the calibration and validation process. The third section suggests which indicators can be proposed, with different degrees of relevance and comparability.

A separate report presents and details the calculation methods, algorithms and module operation development. A separate brochure constitutes the operation manual, in the line of the NOPOLU *Système 2* manuals.

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[5] http://www.gwsp.org/, checked 8/1/2007

[6] EPL is Etablissement Public Loire (http://www.eptb-loire.fr/) and ONEMA Office national de l'eau et des milieux aquatiques (http://www.onema.fr/default.htm) that incorporated the former CSP into it. Former CSP publications heve been extensively used in the developments reported in this paper.

3 Rationales of river fragmentation

3.1 Review of potential impacts of river fragmentation

River fragmentation is a generic term that encompasses diverse concepts, as defined in the introductory part. This section summarizes these different concepts and aims at capturing, for a non-specialist, how they can matter for the environment and how the different aspects interrelate.

The analysis of which elements of each component can be turned into descriptive variables, information and possible indicators with special regard is carried out in the second part of this section.

3.1.1 Relating obstacles to targets

The extended (and operational) definition of “fragmentation” links ‘obstacle’ that cause fragmentation to a ‘target’ that is impacted by the fragmentation. This extended concept makes the relationship between obstacle and target both more complex and more accurate.

The next Table 1 suggests which possible relationship exists between obstacle (class or function) and targets. Three ‘x’ suggest main relationship and single ‘x’ existing relationship.

Table 1: Tentative relationships between obstacle class and targets

		Biota	**Sediment**	**Hydraulics**
Obstacle Class	***Obstacle Function***			
Dam				
	Wall	XXX		
	Reservoir		XXX	XX
	Abstraction	X	X	XX
	Energy production	XX		X
	Water management	X		XX
Cascade		XX		
Natural lake		X	XXX	X
Water quality		X	X	

3.1.2 Changing Hydrological cycles

Water circulates freely in running rivers and remains in the river channel during a certain time that depends on river characteristics and discharge. When a lake intercepts river water run-off, the residence time is modified, that can be measured by the ageing of water (Vörösmarty and Sahagian, 2000). The “ageing” of run-off is expressed as the ratio of effective water storage in reservoirs to mean annual discharge.

The management of reservoirs adds supplementary changes to the average residence time. Reservoir filling is primarily the result of the storage of water at the expense of frequent flood (small floods are smoothed and can be totally removed, thus contributing to the installing of pioneer plant species that grow in the river bed). The operation of reservoir changes low-water regime (minimum flows are stabilised, along with groundwater discharge).

The most dramatic changes are the result of batch energy production, where the local discharge may vary in a short time, with possible impacts on water quality (dilution) and making sharp temperature gradients and hazards for river users. The use of compensation storages mitigates these effects.

3.1.3 Disrupting water flow continuity

Abstractions divert water from the river and may create severe discontinuities in the natural flowing. Some large works divert the larger share of discharge over hundreds of kilometres (Warner, 2000). Many small hydropower facilities divert water on a shorter distance, but the repetition of these diversions may result in long distances on which the river flowing is significantly modified.

Figure 1: Example of dried out river at the gauging station, in relation with the presence of concrete section.

Source: Photo Philippe Crouzet, tributary to the Cebron artificial lake (Région Charentes-Poitou).

In small rivers, water abstractions cause sharp decrease in flow making dry areas in the vicinity of artificial work, even though no damming exists. This issue is poorly documented but probably represent a supplementary threat on small rivers.

3.1.4 Sediment trapping

Sediment load of rivers is fuelled by sediment particles eroded from catchment or from the river itself. The transport mechanisms are extremely complex in their details; on the average, they can be modelled from TSS[7] observations considering water regime (Moatar, Person *et al.*, 2006). In lakes, sediments settle following quite simple laws (Vörösmarty, Meybeck *et al.*, 2003). These laws apply to dammed lakes, but their relevance and application modalities may be questioned if the dam is featured with large bottom gate and is operated to be transparent to sediment fluxes.

Sediment trapping is a very important issue in lakes. Natural lakes are naturally filled with sediments and evolve towards shallow lakes and eventually end as wetland (Pourriot and Meybeck, 1995). In the case of artificial lake, the useful volume may be reduced to a small share of the initial capacity in parallel with dramatic cutting of the input to the sea (Eurosion, 2004), that have to be confirmed by detailed analysis.

Besides the mechanical effects of reservoir filling, the trapped sediments may contain large amounts of unwanted substances, from natural or polluting sources. Erosion of land provides particles that contain bound substances: phosphate and metals, depending for example of the background contents of the soil and subsoil (Salminen, Batista *et al.*, 2005; De Vos, Tarvainen *et al.*, 2006). Contaminated sediments in artificial lakes represent a potential hazard in the event the settled material should have to be released, for example to increase the capacity by dredging, maintaining and upgrading dams features or if the dams is destroyed.

3.1.5 Nutrient trapping

Since reservoirs trap sediment, the substances adsorbed to or constituent of the sediment are trapped as well. The trapping of phosphorus compounds is a major effect thoroughly documented in literature. It

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[7] TSS : total suspended solids

has positive and negative effects since excess phosphorus is removed from further potential eutrophication activity, especially in coastal seas. The exact trapping efficiency is difficult to assess, especially with regards to particulate phosphorus that is linked to rare flood episodes. (**seek for relevant citations**)

Rivers are the main suppliers of silica to coastal sea. This element is indispensable for the growth of diatoms and its shortage is the key limiting factor leading to planktonic successions at sea. Many evidences suggest that impoundments cut the normal supply of silica to the shore seas. In conjunction with the disequilibrium with respect to other nutrients, this fact seems likely to drive the increasing growth of coccolithophores and flagellates, for example in the Black sea because the impoundment on the Danube (Humborg, Ittekkot *et al.*, 1997).

3.1.6 Fish and biota movements

All fish species require the possibility of free journeying along and between river reaches. Amphibiotic[8] species migrate between the open sea and the upstream part of rivers, travelling over hundreds of kilometres. By contrast many species of "resident" fish require a few kilometres to maintain healthy populations.

The different fish species have diverse passing capabilities and requirements: adult salmon may jump more than one metre or swim counter-flow whereas eels may crawl across wet meadows. In all circumstances, each supplementary obstacle retains some individuals, and successfully passing fishes are delayed and consume a part of their energy to go further.

Figure 2: example of small dam equipped with fish ladder

Source: Photo Philippe Crouzet, river Blavet (Brittany)

3.1.7 Habitats changing

River systems (as ecosystems) are not simply channels of water used as routes for fish that can be assessed through water quality and permeability to migrations. It is not the aim of the fragmentation assessment to build a comprehensive ecological approach of rivers: it is neither its mandate nor its possibilities.

However, free-flowing rivers are turned into still bodies of water after damming. This results in a dramatic change in habitats distribution along the river course. The 'lotic' habitats are replaced by 'lentic' habitats. At the end, a totally dammed river is a succession of ponds making a new ecosystem.

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[8] "living in different media", for example salmon grows at sea, reproduces in river and spends it juvenile stage in river.

3.2 Detailed rationale related to ecological issues

3.2.1 Ecological issues under concerns

River systems are important pathways for fish, aquatic invertebrates, terrestrial fauna (river valleys are natural corridors for big animals as they were for human populations) and plants. The direction of travel, the distance travelled and the requisites for effective travel are very different between groups.

Travel is not the only river characteristic under concern. Fragmenting modifies as well habitats and the abiotic conditions of freshwater life:

Hence, it has to be considered from three different points of views:

1. river as pathways that must be travelled without difficulty between specific (migratory fish) or non specific spots (resident fish),
2. river as habitat, assessed as series of running (lotic) and still (lotic) reaches in the most simplified approach,
3. river water content characteristics, which temperature, dissolved gas contents, trophic status and more generally composition and quality are modified by the fragmentation of the system.

The effects of fragmentation are much related to the biology of fish. Amphibiotic fish are severely impaired or eradicated, local migrators show contrasted situations. By contrast, fish from lotic habitats are fostered. This situation is observed in very different geographic situation and has been well documented for the island of Hokkaido, where fishes covering all possible conditions exist (Fukushima, Kameyama *et al.*, 2007).

3.2.2 Long distance migrations of fish

The most important migratory fish in western Europe are the sea lamprey[9] (*Petromyzon marinus* L, 1758); the river lamprey (*Lampetra fluviatilis* L, 1758), the atlantic salmon (*Salmo salar*, L 1758), the sea trout (*Salmo trutta trutta*, L 1758), the twaite shad (*Alosa fallax fallax* Lacépède 1803) and the common eel (*Anguilla anguilla* L 1758). The atlantic sturgeon (*Acipenser sturio* L 1758), as well amphibiotic migrator is considered as “critically endangered” by UICN and nowadays is restricted to a very small share of its initial territory.

These fish combine different types of migratory movements:

- spawning migrations (example: the European river lamprey migrates from its marine feeding sites into river mouths and then far upstream to spawn on gravel beds in the upper reaches, atlantic salmon migrates from see to upper reaches gravel beds, twaite shads migrate from sea to river middle reaches, adult eels travel downstream to join the Sargasso sea, etc.)
- larval and juvenile migrations (example: larvae and juveniles of the twaite shad migrate downstream following their prey organisms, conversely, eels spawn in the Sargasso sea, the leptocephali larvae are brought to the coasts of Europe by the Gulf Stream in 7 to 11 months time and can last for up to 3 years at sea. They are transformed into elvers, enter the estuaries and colonize the continental waters. They evolve into small eels before moving upstream into freshwater basins.)
- feeding migrations (example: young salmons migrate downstream towards the ocean to reach their feeding sites). Not all salmons are amphibiotic, landlocked stocks are present in Russia, Finland, Sweden and Norway[10].

Amphibiontes are the most emblematic species of migratory fish for which there are probably more biological, ecological and observation data available. The ecological constraints on amphibiotic fish are not limited to spawning migration. The two categories of amphibiontes that are relevant for the fragmentation issue are:

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[9] Fish vernacular and Latin names and related indications collected and modified from FishBase http://www.fishbase.org/search.php (checked 16/10/2006) and from ETC/BD communications.

[10] Source : fishbase, http://filaman.ifm-geomar.de/search.php, entry « salmo salar »

- **anadromous** fish that live in the sea mostly, breed in fresh water *(from Greek: 'Ana' which is ‘up’, example salmon)*
- **catadromous** fish that live in fresh water, breed in the sea *(from Greek: 'Cata' which is down, example eel)*

The special case of **amphidromous** fish that move often between fresh and salt water during some part of life cycle, but not for breeding *(from Greek: 'Amphi' which is ‘both’)* is not addressed specifically for the time being. From the fragmentation perspective it can be addressed as anadromous or catadromous.

Fish migrating inside river systems (**potamodromous** from *Greek: 'Potamos' which is ‘river’*) can be processed either as resident fish or as any migratory, with restricted routes. Fish migrating between seas (jargon term is ‘oceanodromous’) is out of concern.

The migration range is generally long (depending on the river size and structure) and may reach hundreds to thousands of km in the river proper, for example in the case of Atlantic sturgeon. The effect of fragmentation is important, even on the salmonids that are the less sensitive fish with respect to obstacles (Aarestrup and Koed, 2003; Gosset, Rives *et al.*, 2006) since they can jump over obstacles or strongly swim counter-flow direction

Fragmentation of rivers by obstacles (e.g. dams, cascades, etc.) is normally considered of major importance for the conservation of fish making important migratory movements. The position of obstacle is a major issue because it drives the proportion of catchment that is locked.

Resting on the migration route through larger rivers may last several days, weeks or months. For such resting, sites suitable for selection include the mouths of smaller side rivers, old side beds, and areas of shelter in shallow water behind islands in the river (if water quality and habitat structures are adequate). In some cases, even harbour basins may be suitable for site selection, depending on the species. Distances between resting sites should not exceed 10-20 km (depending on the needs of the different species) and need a minimum extent of 2-3 km downstream for drift correction. “Drift correction” names the fact that fish may be transported downstream by external factors (floods, fatigue, etc.) and secondary travels back upstream.

Some fish species spend a significant time in river during its freshwater life time. For example, male young eels spend r 6-12 years in freshwater and females 9-20 years, before ending their metamorphosis. Juvenile salmons remain in freshwater for 1-6 years, then migrate to the ocean and remain there for 1-4 years before returning to freshwater. During this time, the fish must find adequate breeding areas, and dispose of enough travel distance. During this period, the fish has the same requirements as a resident fish.

3.2.3 Short range migrations of fish

Every freshwater fish species is migratory to some extent. However the distance of migration varies between species. The following types of migration can be distinguished for these fish species:

- wintering migrations (example: the vairone (*Leuciscus souffia*, Risso 1827) migrates into rivers with deep sections in autumn and returns into shallower brooks in spring),
- drift-correction migrations (example: adults of the bullhead (*Cottus gobio* , L 1758) are drifted downstream with floods; they later migrate back upstream to their former sites),
- lateral reproductive migrations. The most famous example is the pike (*Esox lucius* L) that spawns in inundated meadows or lateral marshes. Pike reproduction is endangered by lateral fragmentation resulting from either dyking and river bed deepening that restricts access to meadows or avoids their frequent inundation. This issue is not addressed in the current fragmentation analysis. In the Baltic, pike is met in brackish waters and could be considered to some extend as anadromous migrator. In river, it may circulate over long distances.

These species have shorter range migrations compared to amphibiotic fish (e.g. a few kilometres at the maximum for the bullhead). Nevertheless, conservation issue is also of major importance for these non-migratory fish species having a narrow migration behaviour (e.g. within the same river, or between the main river and some tributaries) to preserve genetic diversity. The length of possible excursion is not accurately known for the non-migratory species, but several studies on population genetics suggest that distance over 50 km should be acceptable whereas a few kilometres correspond to severe disturbance of population genetic diversity (Knaepkens, Bervoets *et al.*, 2004).

Fishes of interest for the short distance migration should preferably be taken from the list of species listed in Annex II of the Habitats Directive (92/43/EEC) requiring the designation by EU Member States of Special Areas of Conservation (Natura 2000 sites).

3.2.4 Drifting of vegetal species

Riparian areas are constantly seeded from the upstream part of rivers that provided seeds and propagules. The detail mechanism probably involves both transversal and longitudinal obstacles. Regarding solely transversal obstacles, still water areas (lakes, wetlands) settle seeds, delay their travel and possibly jeopardize their sprouting capacities (Merritt and Wohl, 2006).

3.2.5 Water quality issues

Water quality issues in relation with river fragmentation are twofold:

- Obstacle caused by sections where quality is detrimental,
- Water quality changes caused by fragmentation.

In the first case, if water quality is inappropriate to the considered species, it may cause a chemical obstacle to fish migration for example or jeopardize fish life and spawning conditions. Inappropriate quality in this case is not necessarily related to pollution: it may be salinity change of example, in relation to water abstraction or natural conditions.

In the case the quality in relation with pollution, it not necessary that lethal condition to fish to be met: if the fish is no longer triggered to move, the migration fails. These pressures add to the presence of physical obstacles and adverse hydraulic conditions and contribute to lowering the migratory yield.

However, it is likely that most problems should be in relation with the downgrading of water and river bed quality in spawning areas, the survival and hatching of eggs being strongly determined by oxygen content, lack of toxics and organic matters that enhance diseases.

Water quality changes caused by fragmentation are related to:

1. Temperature changes because the presence of impounded water mass: small impoundments tend to increase the downstream temperature; large impoundments change in both directions the downstream temperature depending on the depth and operation of withdrawal gates. Batch electricity production is likely to induce both temperature changes from the discharged water itself and by capturing the heath accumulated in the river banks during the first discharge flow.
2. Dissolved gases that are an important issue in some cases. Dissolved oxygen is often documented and its changes result from the satisfaction of oxygen demand in the impounded waters. The situation is very different considering natural lakes (from which surface water is generally discharged) and artificial impoundments, in which any mixture of water from different depths and oxygen content can be released, following operation rules.

   A special mention has to be done for supersaturation of gaseous nitrogen that occurs in water falling from high elevation that may cause gas bubble disease in fish. In favourable conditions, atmospheric nitrogen is forced to dissolve over saturation and causes embolism in fish situated downstream (US Fish and Wildlife Service, 1992). This hazard is not much documented in Europe, possibly because this problem does not occur or has not been observed despite it has been reported since the 1960’s in North American rivers.
3. Eutrophication of impoundment. Impounded water are more sensitive to eutrophication processes than running waters and water quality downgrades more for the same quantity of excess vegetal material.

3.2.6 River habitat changes

River slope is a key factor of ecological conditions for fish and this factor was demonstrated as having paramount importance across Europe (Pont, Hugueny *et al.*, 2006).

Lentic (standing-water) ecosystems are usually characterized by large deep basins with little or no flow existing within the basin. A lotic[11] ecosystem is any spring, stream, or river viewed as an ecological unit of the biotic community and the physiochemical environment.

The difference between lentic and lotic habitats is not always clear-cut. The decisive criterion is the length of time a given mass of water resides within a certain part of an aquatic ecosystem, a concept clearly related to flow rates or residence time. Some large rivers with only a slight gradient have low rates of discharge and flow and extensive floodplains with many interconnected bodies of lentic waters.

An operational distinction between lentic and lotic systems is to consider that all rivers systems, out of lakes and ponds are lotic, whereas all reaches inside lake or pond are lentic. Lakes and ponds are arbitrarily defined by the presence of any obstacle higher that a selected threshold (e.g. 50 cm). The assessment of the length of reach turned from lentic to lotic (and conversely) is made by GIS processing, unless direct information is available.

Summarizing, an overall indicator can be calculated considering the relative proportion (and changes in proportion) between the *lotic* length and *lentic* length of river courses.

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[11] Definition modified from http://www.uwm.edu/~ehlinger/background_information.htm

4 Defining fragmentation descriptors for fish

4.1 Building fragmentation indicators from fragmentation descriptors

4.1.1 Operational definitions

The EEA carried out, with the assistance of a consultant[12], the development of a fragmentation calculation module to provide relevant *descriptors* of river fragmentation that could be used as building bricks to compute *indicators*. When possible, especially if the ancillary descriptors required for indicator calculation are accessible from the module manager, indicators will be computed as well.

In this case, “descriptor” calls information that is based on a direct measure, whereas an “indicator” tends to inform about a complex situation which is not necessarily observable. A review of environmental indicators and their meaning has been done by the EEA (Smeets, Weterings *et al.*, 1999).

“Fragmentation module” calls the specific calculation module under NOPOLU *Système 2* that is developed to produce the required descriptors from the relevant environmental variables by processing data related to obstacles (dams, dykes, quality, etc.) adequately placed on the routed river system and using catchment related data. This module has been developed to be run as stand-alone as well as incorporated to the NOPOLU *Système 2* platform to enhance its portability.

The analysis of fragmentation is inserted in a global approach of hydrosystem issues, currently under integration on the “spatial platform”, called SPAICE.

The fragmentation module uses ancillary information such as river quality, river discharge, soil characteristics, land cover, etc., that are not part of the module and are used as well in specific applications.

The fragmentation module is designed to compute descriptors relevant to three classes of fragmentation issues (sediment, biological components and hydrology), in a way consistent with the environment accounts requirements. These requirements impose to provide different time states and data required to analyse the pathways between the initial and final states. Practically, that means that the temporal dimension must be processed and that the actual location must be processed and stored.

The different requirements are analysed in the topic reports. This report deals with fragmentation impact vs. biota, with main regard to fish.

4.1.2 Coping with the historical dimension

Obstacles are all defined by a position (coordinates, name, river of placement, etc.) and date. Both information are essential to the analysis of fragmentation because the exact position drives the upstream-downstream relationship and date the development of fragmentation impact along time.

The positioning of obstacle is the most demanding feature when considering the performance and the building of the calculation module. The calculation methodology naturally consists in placing all obstacles on the GIS, disregarding their date and processes their impact at a certain date, considering which obstacle existed at this time.

This approach is as well very realistic because any obstacle exists only between T0 and T1. The first dams still in operation were built in the second century, some dams have been destroyed. Even natural lakes may have short term history in specific conditions.

Artificial obstacles are the most related to historical issues when considering the practical range of calculation (c.a. 17th to 21st centuries): dams are created and decommissioned, locking dams become equipped and their operation rules adjusted to exploit this equipment in the most suitable way, quality barriers are suppressed because of the development and operation of waste water treatment plants, etc..

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[12] Pöyry, Gestion des ressources en Eau / Water Resources Management 2, Boulevard Vauban 78180 Montigny-le-Bretonneux FRANCE

Hence, the historical dimension is of paramount importance to understanding the role of the different obstacles and the development of their presence with time.

The time resolution of the calculations cannot be better that the year. In fact, the actual time resolution is greater that the year because year is the accuracy of stored figure, not the accuracy of the event described. Some dams have needed over 20 years to be completed (e.g. the Inguri dam in Georgia, the tallest one recorded in the geographical domain covered by Eldred2.

Eldred2 stores the commissioning year along with the years when some change has been recorded, thus improving the information and it manages as well dates of operational changes (e.g. fish transfer across the dams operated from year Yt to present)..

The main sources of uncertainty are:

- The year may be inaccurate; different sources equally trustable provide different figures as “first year”, possibly because a significant lag may exist between official commissioning and actual operation,
- Many impoundments are first filled over a certain years time, for security reasons or just lack of water (in dry areas, the refilling time may reach more that a decade), thus making sensible difference between commissioning and operation,
- Destroyed dam, nevertheless making obstacle are not registered as such,
- Planned and abandoned dams are present in some registers, despite they have never been erected,
- Commissioning date is not provided or fuzzy (“… before 1789[13]…”). This is a very troublesome case, making it possible to compute inaccurate results.

At the end, calculation should be done both for single years and for a range of years, that are likely to be more comparable.

The very large number of possible obstacles and their attached time event required specific design of the calculation module to minimise the calculation time requirements. This is analysed in a later section.

4.1.3 Computed descriptors

Migratory fish

The two relevant categories of migratory fish (anadromous and catadromous, definitions in §3.2.2) are characterised by a limited set of descriptors. The most complex is related to anadromous, because adults may travel upstream, then go back downstream and juveniles travel downstream:

1. most distant point reached within the route, in both directions for adults and juveniles, considering that obstacles may be different considering age class and direction. This information is completed by the code of the obstacle (or set of obstacles) making a lock in each branch of the route at a certain date.
2. proportion of fish reaching that point, by age class and direction, that explicitly depend on obstacle permeability and complementary characteristics,
3. if possible, physiological status of fish reaching place,
4. conditions for fish during its river part of its life cycle (it is then considered as resident in a certain area).

The ‘route’ is the set of river stems normally visited by the fish, within a large basin in principle ending at sea. The knowledge of the accurate routes is a matter of adjustment, because it implicitly refers to a certain historical condition. Ideally, the descriptors should encompass a series of years to capture positive and negative changes in fragmentation. Long distance migratory species historically colonised parts of the river system, but not all parts. All amphibiotic migratory species had a territorial extending

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[13] In France the jurisdiction is that a river work is assumed permitted if made before the 1789 revolution, the mention is “fondé en titre”, the actual date of building can be several centuries before 1789.

from sea (or other terminal recipient, e.g., large lake) and covering rivers and brooks of the catchments suitable for their biological needs.

The different items in the list above are driven by the fact that sustainable long distance migration requires three conditions. First of all, the amphibiotic journey should be possible between a downstream point and a series of upstream points or between a series of upstream point and a single downstream point according to the direction of migration. Second, the fish having reached its target are should benefit of a certain area (distance) of river around the target and third, it must find appropriate living conditions during its river part of its life cycle.

From the calculation point of view, this is carried out in two steps, the second being application to migratory fish of the requirements related to resident fish.

Question to solve are:

- Knowledge of these areas, as reference areas, and extension of the concerned rivers,
- Insertion, coding and processing of this data in the model.
- Assessing proxies of relevant information where analytical data is scarce.

Regarding most species, the uppermost historical extension area is generally known and published in literature. However, “published” does not mean “available as GIS feature”. A large deal of work is required to turn scientific information into calculable data.

A key problem requiring decision is the share of the fish numbers at confluences, as illustrated in the example displayed in Figure 3 where rivers in thick colours only are related to long distance migratory: blue is not fragmented; green is not fragmented between obstacle 1 (upstream) and obstacle 3 (downstream). The question is: what is the fish population pretending to reach respectively left and right branch of the river system?

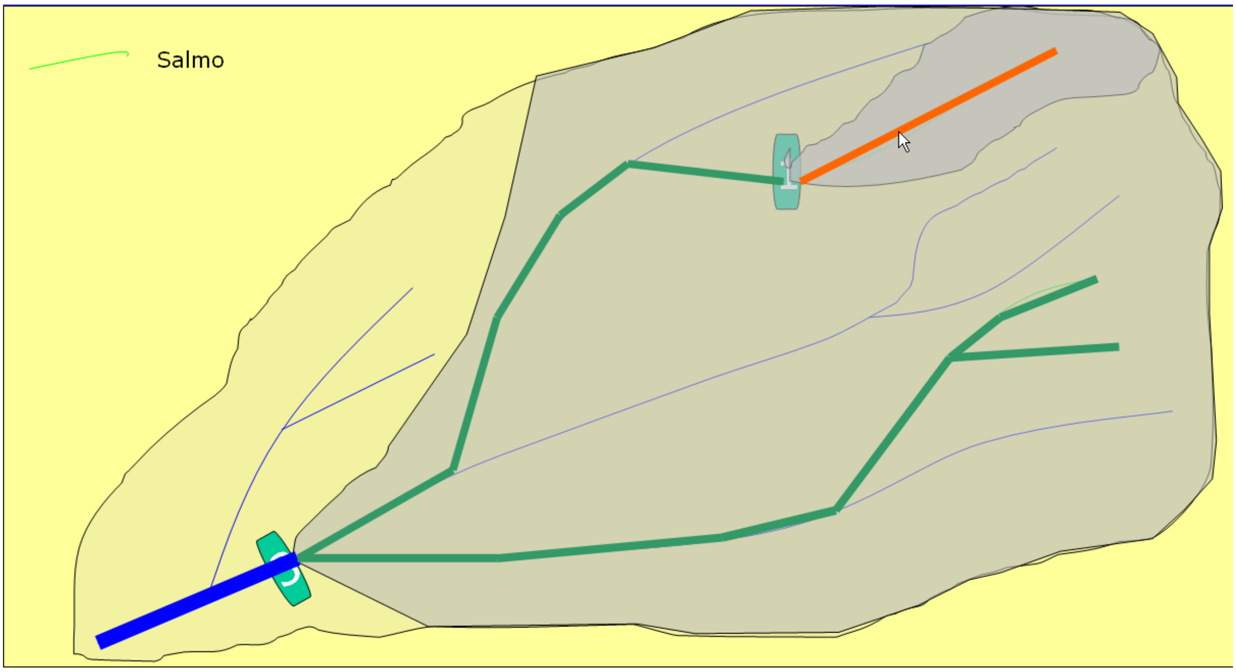


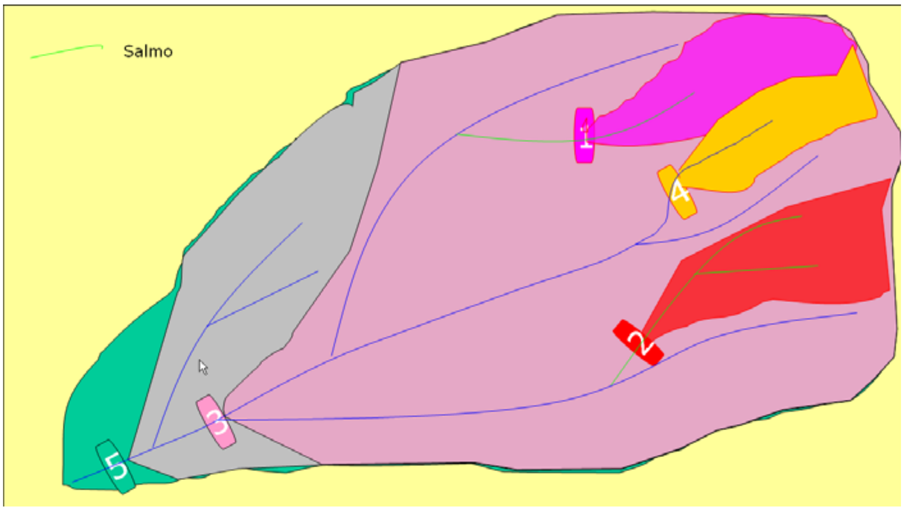
Figure 3: Schematic illustration of the confluence issue vs. upstream migration

In details the appropriate conditions are far more complex; it is important to note that the travel success is necessary but not sufficient conditions for overall success of the amphibiotic life. A very difficult issue for anadromous fish is the finding of suitable spawning conditions, which are not portrayed by the passing success. For example, the spawning areas suitable to Atlantic salmon are in the upstream parts of rivers where the bottom is made of clean gravels, ensuring oxygenation of hatched eggs. If series of easily passable dams significantly diminish the length of free-flowing conditions in these areas, the reproductive stage mail fail, jeopardizing the whole life cycle. Hence, it is not enough to consider the migratory stage alone, local part of the cycle and downstream migration must be considered as well. The target of the calculation module is to capture as much as possible all parts of the cycle, possibly with different degrees of accuracy, as discussed later.

The portion in orange, upstream obstacle 1 on the right branch marks a section which reaching results of passing two obstacles for fish journeying upstream the right branch. Fragmentation calculation has to deal with the initial extension only when comparing pristine and final situation.

Resident fish

Resident fish is understood to travel permanently in any direction within a certain area or sub-area of a certain basin. The travelling descriptor is the free circulation area, understood as the sum of lengths of rivers stems that can be freely accessed from any point in the catchment. The term ‘freely’ must be understood as ‘*not limited by obstacle bigger than the threshold defined by the fish species under examination*’. As computation, resident fish makes migrations that have no starting point and no ending point. Practically, the free-travelling river lengths are exemplified in Figure 4.



The schema represents final stage, assuming that obstacles were installed in the orders 1 to 5. The computed distances at the end are:

1. outlet to 5 (green catchment),
2. 5 to 3 (grey catchment)
3. 3 to [1, 4, 2] (light pink catchment)
4. 1 to top (dark pink catchment)
5. 4 to top (yellow catchment)
6. 2 to top (red catchment).

At the end, the unique catchment having L km of river is turned into 6 sub-catchments, each having L1 to L6 kilometres of free travelling possibilities.

Figure 4: Example of distances between obstacles

Different descriptors are adjusted to the characteristics of each obstacle. In the given example, the situation is very simple because:

- No indication is given in each sub-catchment of the distribution of rivers by order (proxy of size class),
- All obstacles are considered equal and being absolute locks if they trespass fish capability within a certain calculation scenario.
- Fish population is assumed as being the same in all part of the system.

By contrast with the case of migratory fish, the cumulative effect of obstacles is not taken into account; this would be meaningless since an obstacle is a lock or not for a certain fish type.

The “resident fish” assessment has lead to the concept of “generic fish” that is a fish not related to a known specie that has dome passing characteristics. To simplify they are designated as “Fishxxcm” indicating the threshold height such fish can pass. Being not related to a species a generic fish has any practical distribution area, making it superfluous to analyse a reasonable distribution are before proceeding to calculations.

In the current version of the application, calculations require a considerable amount of time, that makes it necessary to consider optimizing the calculation method.

5 Modelling Fish passing descriptors

5.1 Modelling rationales

Modelling addresses fish populations, not individuals. Population numbers (how many individuals will show at a certain river point) are unknown, and have not been included in the modelling that therefore processes proportions and not numbers.

However, the number of individual must be to some extend be taken into account. This is especially the case when addressing migrations, because each confluence apportions the population (when upstream migration) or combines populations (downstream migration). Where the preferences are known, they can be documented, otherwise fish is apportioned between branches according to default settings (50% each or in proportion of catchment area upstream).

This preference factor is very different to obstacle permeability discussed below.

When reaching a obstacle, three main factors apply:

- A certain proportion of the population is retained (is generally mortality, this is expressed as ‘permeability’,
- The individuals that pass are, on the average, delayed, this is the ‘delay’ variable,
- The individuals require a certain energy to pass, on the average, they lower their physiological status and accumulate tiredness, this is the ‘fatigue’ variable.

Modelling obstacles impact on species movement can be done by combining the three factors that apply either to terrestrial or aquatic biota, summarized by the acronym “PDF” in further sections that apply to the couple obstacle × species (by age) and the preference proportion applied to routes.:

5.2 The PDF (permeability, delay, fatigue) variables

- “**Permeability**” expresses the proportion / rate of individuals that can pass the obstacle way up and way down (possibly complemented by confidence interval or contextual variables related to discharge for example).
  Permeability is site, specie and direction dependent

  On a river branch, permeability is a multiplicative factor. For example, if 3 obstacles allow each 50% of passing, hence, upstream the 3rd obstacle only $0.5^3 = 0.125$ (12.5%) of the initial population is present, in the absence of confluences.

  Permeability is calculated for each single river stem, starting from the most downstream point under concern when travel direction is towards upstream reaches. It is assumed for computing facilities that if fish (only fish migrates upstream in the river) has to pass obstacles, it will apportion between the different branches at a confluence, if both belong to its migratory pattern.

  Final permeability can compare to a target migration yield per specie and catchment, which numerical values have to be defined. The calculation stops when impassable obstacle is reached (P=0) or when the residual fish population proportion falls below a settled threshold (e.g. 0.01%)

- “**Delay**” expresses the average lag that the obstacle is supposedly inflicting to the journeying of species (possibly complemented by confidence interval or contextual variables related to discharge or season for example). Delay is **site, specie and direction depending** and is designed for possible correction by hydrological characteristics in a next version of the calculation module[14]. Delay is an additive variable, expressing that delays cumulate along the journey.

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[14] For the time being discharge is not available, hence modelling delay as f(discharge) is impossible.

As mentioned for permeability; total delay is relevant for each river stem. Total delay can compare with a range of acceptable delays that is understood as not incompatible with the success of the migration.

When a threshold delay is reached, the migration is interrupted because excessive delay is equivalent to impassable obstacle.

- "**Fatigue**" is a variable introduced at the initiative of ETC/BD that represents the share of energy / physiological capacity consumed by obstacle passing. This variable was introduced because the delay alone should compare with date (does the migrators achieve their journey too late?). By contrast, fatigue can represent the fact that despite on time, the physiological condition has worsened and that the journey is unsuccessful.

  Fatigue is therefore a subtractive variable that consumes the initial load or reserves. Expression is %.

  The fatigue share is **site, specie and direction depending**. Fatigue can be used as well as calibration variable: when the reserves are exhausted, migration ceases disregarding other factors.

  When dealing with seeds and propagules, fatigue represents the capacity of sprouting and practically expresses the remaining proportion of viable seeds.

  When the energy reserve of fish is exhausted (or below a threshold) the migration ceases because exhausted fish migration is impossible and equivalent to meeting impassable obstacle.

The three factors mentioned are very general; their application may require assumptions and simplifications in some cases that are considered in the paragraphs below in the cases of long-distance migration, short-distance (e.g. resident) fish and propagules transfer. Invertebrates drifts are not considered at this stage.

The factors permeability, delay and fatigue are modelling facilities that were introduced to analyse finely the different configurations. It is well known by fish experts that a series of obstacles that can be easily passed only in exceptional conditions, hence making long delays on average years, is as jeopardizing for migration as few obstacles that are difficultly passed. These passing variables that capture a simplified reality are seldom monitored or expressed as such for any obstacle.

The next section presents the way that was selected to use available information and turn it into modelling variables.

5.3 Populating PDF data from available data

5.3.1 Process rationales and method

Passing characteristics are, as mentioned above, obstacle, species, age and direction depending. It is beyond any reasonable hope to collect all these data that would represent c.a. 3 million data (50,000[15] dams × 20 species × 2 directions × 1.5 ages (all species together)).

Hence, most passing variable must be modelled under reasonable scenarios, based on all existing and relevant data. Besides, the modelling procedure must be as transparent as possible and stick to observed data where possible.

A specific procedure has been developed. It has the advantage of making species depending from the anonymous dam characteristics. Hence the final PDF values are to some extend species depending. The linkage is for the time being direct with respect to dam height, the relationship is not made when considering delay and fatigue that are perhaps quite depending on hydrological conditions as well.

Calculations are carried out per dam and per species to model. The flow chart in next Figure 5 sketches the essence of the process; the detailed programming is quite complex. The key principles are that each dam data is computed to model a passing code which is replaced by observed code (if present, for the species). The passing code is then updated according to dam specificities and PDF values modelled.

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[15] Underestimated value including expectable "small dams" in Europe, the large ones being of little importance from data collection point of view: most of them are just locks.

In a last stage, if PDF values are present in tables for the dam and the species, they update the modelled values. This process has been set up to simplify programming because observation data may be present for only an age related to a species and for certain dates only.

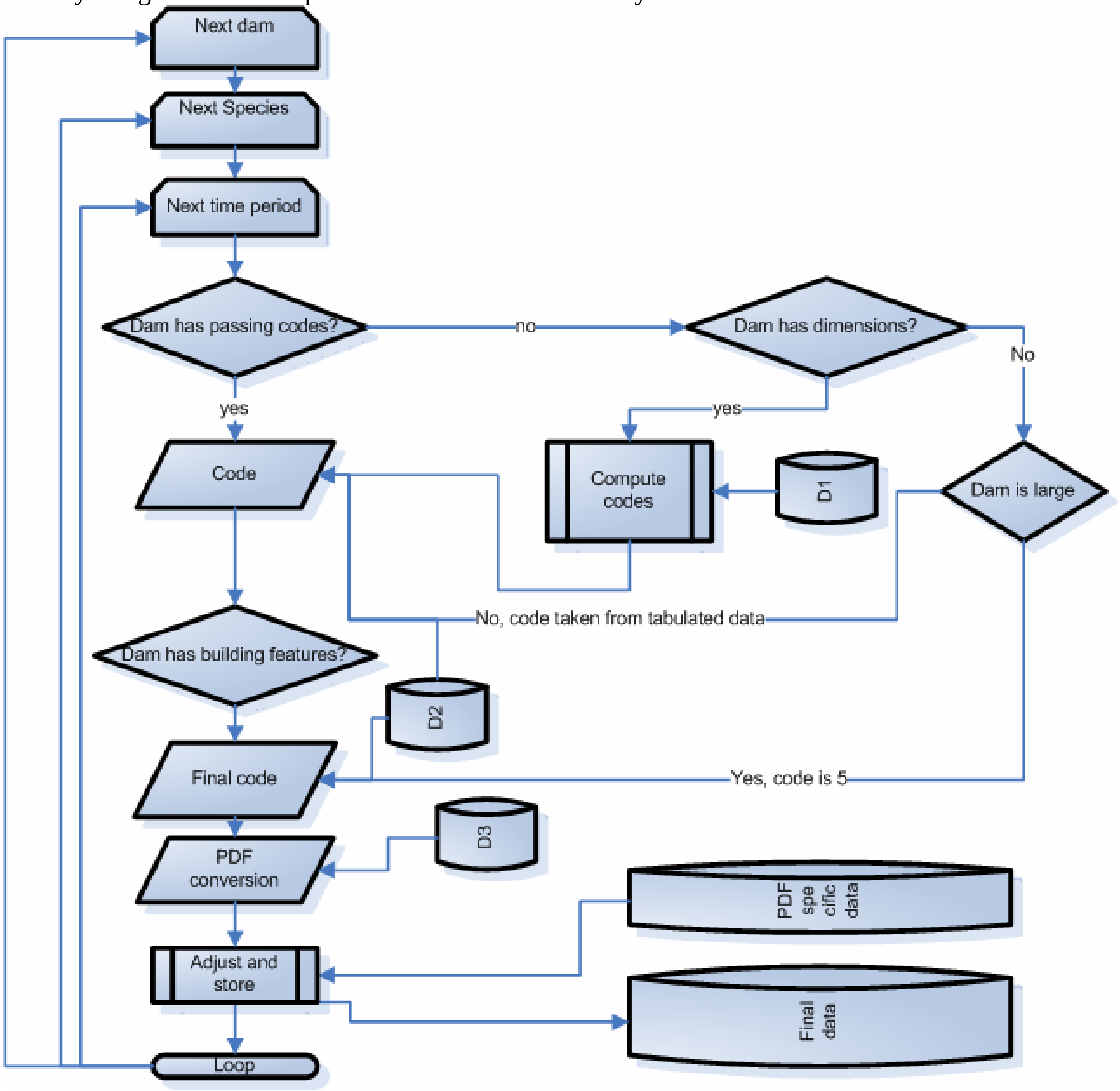

Figure 5: Flow chart of PDF variables simulation process

The different sources and modelling methods are discussed below.

5.3.2 *Validated source of information for passing codes*

The main difficulty is that few organisations attempt capturing passing variables at the catchment level or with the view to fuel models. Data is more often collected at the site level, for regulatory purposes.

In France, many efforts were devoted to establish the passing conditions for as many dams as possible. This work was carried out by the *Conseil supérieur de la pêche* (CSP[16]) that investigated hundreds of non-large dams. The efforts were focused on non-large dams because most if not all large dams are fully impassable obstacles that do not require expert judgment.

The methodology developed by the CSP to assign passing capabilities to large number of dams was based on the analysis of fish passing and further assessment of the obstacle as 6 classes, noted 0 to 5

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[16] The CSP has been merged into the new ONEMA (Office National de l'Eau et des Milieux Aquatiques = Notional office for water and aquatic media), installed in 2007

(Conseil Supérieur de la Pêche, 2005). These passing classes can be assigned, by decreasing order of accuracy:

- Following deep analysis of passing success,
- From dam inspection and calculation from its characteristics (with comments),
- From dams characteristics,
- From default values.

Table 2: Fish passing codes

Code	CSP definition	EEA assessment as baseline P and D values	Comments
0	absence of obstacle	(100%, no delay)	Code 0 is not modelled, and is considered as full absence of obstacle or total erasing of the obstacle.
1	obstacle exist, easily passed, is not obstacle	(99%, no delay).	Code 1 is understood as making no obstacle for capable fish, and is modelled.
2	Some delay possible,	(>95%, delay <=1 week)	
3	Some difficulties	(80%, 2-3 weeks delay)	
4	Passed under exceptional conditions	(<50%, delay ~5 weeks)	
5	Impassable.	0%, delay infinite, Fatigue maximum (for consistency)	
9	Is not CSP code		Added as transitional joker

Source: translated and adapted from CSP report (Conseil Supérieur de la Pêche, 2005). Joker « 9 » has been added for processing facilities

Following CSP assessments and former studies (Dagreve, 2005), dam characteristics significantly modify the passing codes values. For same height, a sloppy dam with irregular down face is passed easier that a smooth vertical work. Similarly, other characteristics increase or decrease the passing capabilities. Synthesising CSP data and dams types described in the different sources of dams end up with a correction table reported below, with dam types as inventoried and coded from different databases.

Table 3: Dam types recorded and adjustment of standard passing codes

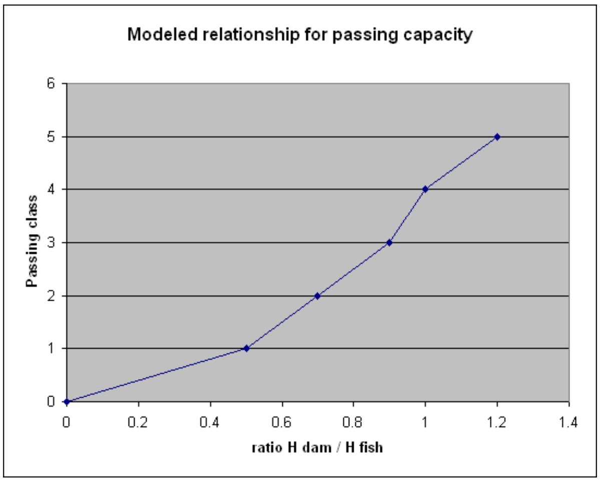
Dam construction type	Adjustment to the passing code	Codification of dam type
Anti-lift system	0.50	AL
Barrage	-0.50	BM
Buttress	1.00	CB
Rock fill	0.00	ER
Lifting sluice	-0.50	LS
Log weir	1.00	LW
Multiple arch	1.00	MV
Gravity in masonry or concrete	1.00	PG
Pin weir	-0.50	PW
Slope invert	-0.50	SI
Slope spillway	-1.00	SS
Earth	0.00	TE
Tilting Valve	1.00	TV
Arch	1.00	VA
Vertical invert	1.00	VI
Vertical spillway	1.00	VS
Unlisted	0.00	XX
No data	0.00	ZZ

Source: Eldred2 database (EEA) as populated from CSP works and other sources

The existing documentation in the data base (for large and non-large dams) ranges from full documentation to just presence of dam without dates and characteristics. To populate PDF data in a flexible and comprehensive way, an adequate procedure has been implemented in Eldred2. This procedure first calculates standard values and then updates where detailed values are present for each dams and for certain species as sketched in Figure 5.

The main problem to face is to populate values for different dams for which only dimensional characteristics are present and that have no observed passing codes. It has been assumed that within a certain range of height, a dam is all the more difficult to pas that its height gets closer to the maximum capabilities of a fish species. Hence a calculation involving the ratio of fish 'jumping[17]' capacity expressed in metres to dam height provides a proxy of the passing code.

All numeric values are under scenario definition, thus allowing different tries and calibration. Regarding the distribution of ratios, it was assumed that the difficulty is not proportional to the ratio. This is illustrated by the graph that reports the standard values taken as first scenario.



Comments:

The graph expresses the guessed relationship between fish capacity (expressed as estimated maximum jumping height H fish), dam height (H dam) and passing code. Up to 50% of maximum height, dam has little effect (code 1, see Table 2). Up to 75%, the effect is still limited, yielding code 2, that has little single impact, but may act as cumulative stress and delay. When the 100% is reached, code 4, allowing exceptional passing is set. The total locking, code 5 occurs at 120%, that accounts both for uncertainty on H fish and H dam respectively estimates and values.

Figure 6: Example of modelled passing class *vs.* the ratio between dam height and fish maximum passing height

The presented values are tentative that have to be tuned with specialists and after model runs. For the time being, they have been selected from discussions with experts, personal knowledge and FishBase[18] indications.

Table 4: Passing thresholds and default values per fish species

Scientific name	Common name	Migratory?	Migration direction	H max in upstream way	H max in downstream way	Default passing code upstream way	Default passing code downstream way
Acipenser sturio	Sturgeon	Yes	A	0.8	0.5	3	3
Alosa alosa	Allis shad	Yes	A	0.5	0.5	3	3
Alosa fallax fallax	Twaite shad	Yes	A	0.5	0.5	3	3
Anguilla anguilla	European eel	Yes	C	1.5	3	3	1
generic twenty	generic 20cm	No	R	0.2	0.2	4	3
generic fifty	generic 50cm	No	R	0.5	0.5	3	2
generic hundred	generic 100cm	No	R	1	1	2	2
generic any	generic fish	No	R	2.5	5	3	2
Lampetra fluviatilis	European river lamprey	Yes	A	0.5	0.5	3	3
Lampetra planeri	European brook lamprey	No	R	0.3	0.3	3	3
Petromyzon marinus	Sae lamprey	Yes	A	0.5	0.5	3	3
Salmo trutta fario	brown trout	Yes	A	1	2	2	3
Salmo salar	Atlantic salmon	Yes	A	2.5	5	2	3

Source: extract from Eldred2 table. Scenario code and operating codes removed for clarity

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[17] The term 'jumping' is placed between quotes because not all species actually jump, it has to be understood as a generic term for active passing.

[18] http://www.fishbase.org/home.htm, checked August 2007

The current values taken for first scenario reported in Table 4 provide the maximum heights assumed as passable for a standard dam along with the passing codes used when dam height is not populated. The fish species comprise “generic fish” characterized by their passing capacities. The “generic fish” notion has been considered after discussion with ETC/BD because it helps defining indicators over a wide range of areas where vicariant species are met.

Discussions with experts strongly suggested that the different uses of dam and its management significantly alter its passing possibilities. The possibility is kept in Eldred2 to adjust results with the uses, but this has not yet been implemented because rules and corrections to apply are unclear. It seems that electricity production is the most problematic and that navigation dams (where gates are opened several times a day) are less. Old mills used for mechanical energy are understood to have been more transparent in the past times, when they were frequently operated and managed. Most are now turned into residential properties and the locks are no longer or seldom operated, making them almost impassable. This difference in result as depending on behaviour of the owners has not been modelled too, since calibration data is lacking.

At the end, the modelling rules give some possibilities of passing, the effective closure of travel being more depending on the succession of passable dams that on single locking one. This shall be adjusted in the future, if it appears as an important feature to correct.

At the end, passing classes are turned into PDF values using code to PDF characteristics. For the time being, and considering the uncertainty of data (the procedure is used where no passing code is available for a dam) the relationships are not specie depending. This is open to further discussion, the informatics is not a problem but populating codes might be.

Table 5: Passing code to PDF relationships (tentative values)

Passing code	P, upstream direction. No unit	D, upstream direction. Weeks	F, upstream direction. No unit	P, downstream direction. No unit	D, upstream direction. Weeks	F, upstream direction. No unit
0	1	0	0	1	0	0
1	0.99	0.1	0.01	0.99	0.1	0.01
2	0.95	1	0.05	0.95	1	0.05
3	0.8	3	0.1	0.8	3	0.1
4	0.5	5	0.4	0.5	5	0.4
5	0	99	1	0	99	1

Source: extract from Eldred2 table. Scenario code and operating codes removed for clarity

The calculation procedure and table populating facilities, scenario management, etc. are reported in the Eldred2 manual.

5.4 River GIS and fish routes

5.4.1 Specifications

A calculable river system comprises two sets of objects: the geometrical objects that represent the rivers, the canals, the watersheds with certain accuracy according to the chosen resolution (in relation with the scale of representation). These geometrical objects are enough to represent the system as a map. To make it calculable, a hydrographic model must be present as well. It logically connects all the objects together and expresses the way to travel between nodes. For the time being, the hydrographic model that backs the geometrical representation has some restrictions: defluences (e.g. branches in a river delta) are not permitted; braided rivers should be represented by a single route; river is modelled by a line; lakes must be fitted with a virtual river to ensure continuity of the hydrographic network, etc. In a calculable river system, the river is eventually represented by a line with no width. This is a simplification of the reality since many European rivers may have hundred metres of width, hence posing problems in snapping objects as discussed below.

To be operative, the river system must fulfil another requirement: the important objects must be attached to it and their logical relationships kept. However, the sources of information are independent. For example, dam positing is carried out independently of river description. Hence, the best way to ensure relevant snapping of dams on the rivers is that the geometrical accuracy of both sets be compatible and good. This requires, apart the best precision in the geometrical coordinates:

- ✓ Enough rivers included in the system so that as few objects as possible remain orphans at the end of the snapping process,
- ✓ Not too many rivers to avoid false snapping because of the intrinsic approximation related to the simplification of both rivers and dams to point, hence making it necessary to snap them using a buffer area.

The same requirements apply to all classes ob objects to attach to rivers: monitoring points, abstractions, diversions, discharges, etc. All the requirements, partly contradictory make it necessary to develop the river system stepwise and build it from the most appropriate sources, balancing pros and cons of the different possible sources.

Basins

The requirement for "basins" in a wide acceptation is limited to the possibility of segmenting calculations in as many practical entities that are not depending form on another.

The concept of basin, as interacting with fish issues, meets several objectives:

1. they are the aggregating level for reporting certain fragmentation issues, and must therefore match (to some extend) with the administrative units defined by legislation,
2. they are the areas from which some fish have been eradicated because the presence of insurmountable obstacles,
3. they are the targets for some fish routes,
4. last but not least, they are the building units of the river systems.

Rivers

A river is defined by all the segment of drainage system that have the same name under the conditions listed below, "name" having again a wide acceptation (Oder /Odra is the same name, Rhin/Rhine is the same name, Escaut/Scheldt is the same name). In practice the spelled name does not operate correctly and the "name" must be coded as a unique river continuity identifier, called CGNELIN in the model software.

The major requirements that should be met to make calculations possible are:

1. River area must be represented by a single line and the position of this line (sketching the main flow central line) must be as accurate as possible to allow automatic and accurate snapping,
2. River segments drawing that line must be connected and "flowing" in the good direction
3. River segments must be routed. A "route" is the information that allows selecting all segments of river X, through the same CGNELIN.

If the route is not documented, it can be built externally from the uppermost segment of the route until the confluence with another routed system. River name is a prerequisite to constructing accurate routes from river segments. Routes and main drains of catchments are related information that does not substitute however.

In the case of the Loire river basin used as pilot, data source is derived from the BD Carthage, simplified to the main drain of the "Zone hydrologiques" that are the smallest functional catchment delineated in France by Cemagref. The BD Carthage is fully compatible with the ERM (Euro regional Map) now used by the EEA as source of its river systems GIS.

The consultant in charge of developing the model had however to correct many errors; hence the final river GIS used in the pilot is not strictly the source provided by Cemagref.

5.4.2 Historical extension and meaning of fish routes on the river GIS

Amphibious migrators

Modelling the fragmentation of routes used by migratory fish has two prerequisites:

1. the river network must be detailed enough to include the routes,

2. the historical extension of fish must be known.

Both constrains are important, with special regard to the first one that drives the possible scenarios for the second: if the GIS is incomplete, modelling is just impossible whereas scenarios of routes can be easily added thanks to calculation module facilities.

Both requirements are fulfilled separately. The GIS is addressed by the EEA and the ETC/LUSI . The current developments aim at incorporating the ERM (Euro regional Map) based on the 1:250K topographic maps made by the European geographical institutes combined with large catchments defined from the JRC CCM2 river and catchment modelling as envelopes and, when possible, national data sets as accurate catchment delineation to be in line with the WFD reporting..

The current trial application was developed on the river Loire catchment and used the currently available river GIS, simplified from the French BD Carthage, which is the source of the French ERM. The genuine BD Carthage resolution is 1:50K, which is far too detailed for the purpose of the fragmentation.

The impact of GIS resolution on the accurate assessment of the different descriptors is discussed in another section.

Regarding the extension of historical routes, this work is under development by ETC/BD. Most important species: Atlantic salmon, Atlantic sturgeon and European eel have been the subject of in-deep works by European teams that make it likely to find relevant data.

The expected information is the historical observed routes potentially and historically used by the different fish migratory species, expressed as river stems and catchments.

Similarly, resident fishes domains are related to catchments in which those fishes were normally present. The format of the information is closely related to the structure of the rivers and catchments system used for calculations.

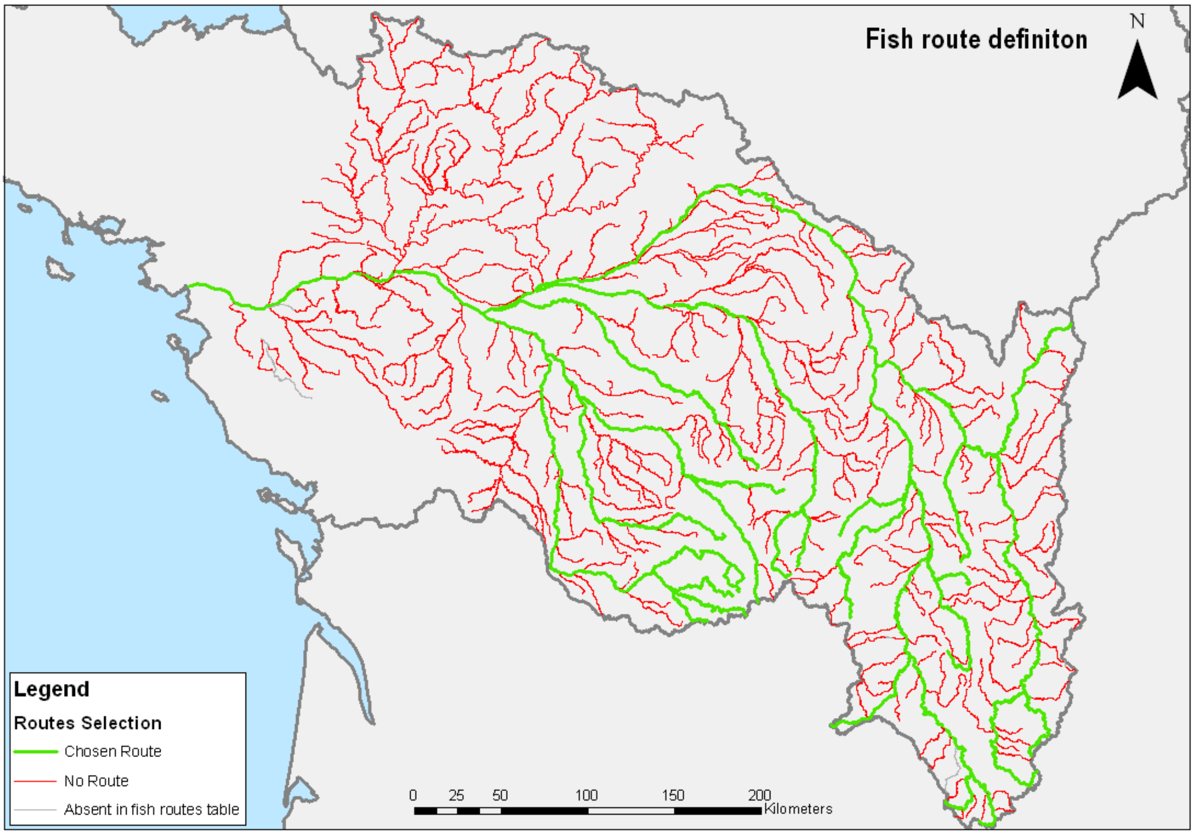


Figure 7: Current routes settings for atlantic salmon on the Loire catchment.

Source: adapted from Steinbach, see text)

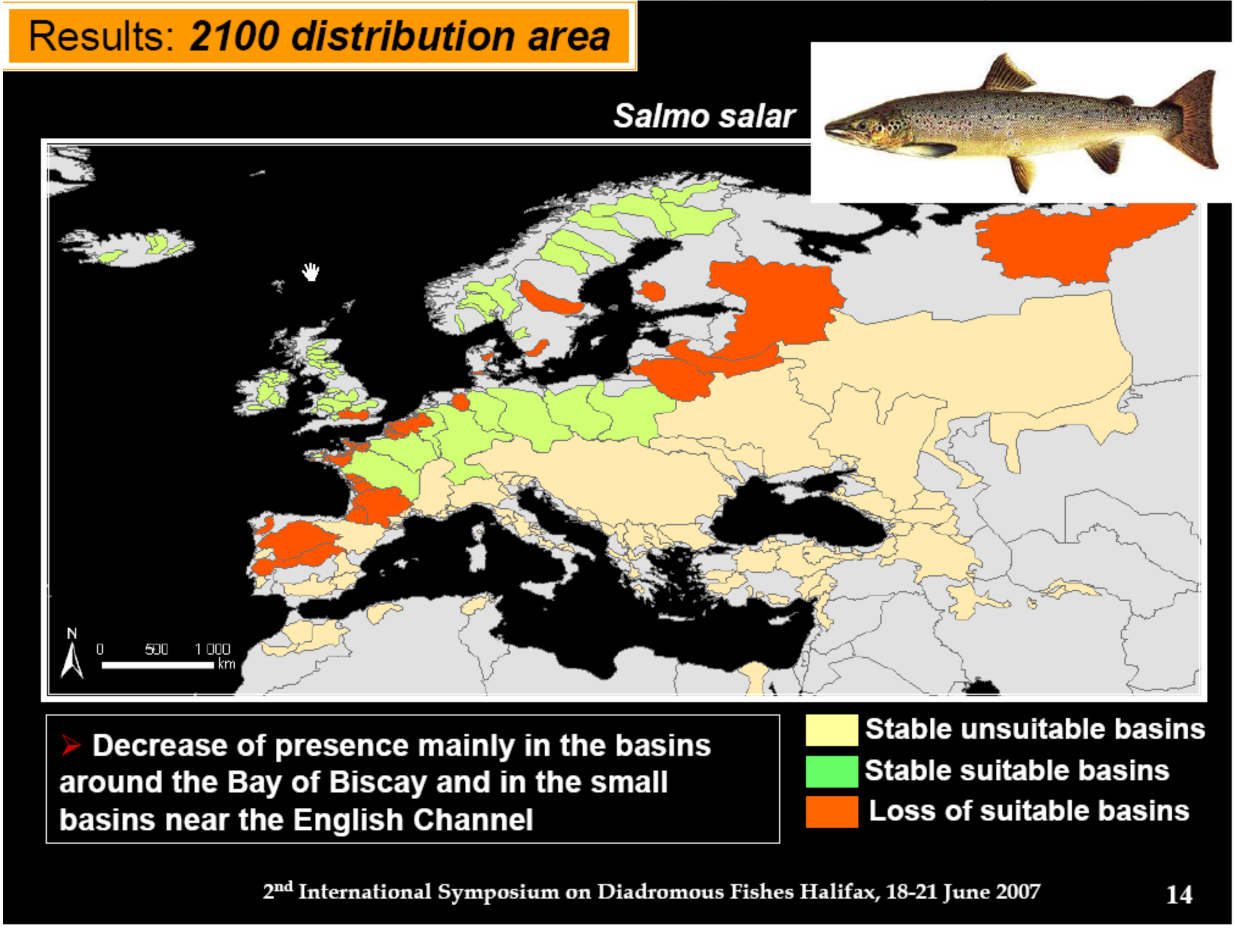
The trial application was based on the work by CSP, as prepared by Steinbach (Conseil Supérieur de la Pêche, 2005). The routes as indicated were turned into calculable sets and display as follows. In the current application, a “fish route” is any set of connected (or set of sets of rivers disconnected) declared as such. They represent the maximum potential excursion of a certain fish in a certain direction. Hence, downstream to upstream (codes DtoU) and Upstream to dowmstream (codes (UtoD) are different route scenarios that must be computed separately.

The computing system allows declaring as route any river topologically connected. In the Figure 7 above, all rivers in thick green are declared as possible routes whereas the thin red rivers are not declared. They could become routes under a different or corrected scenario.

Computing proportion of fish reaching the uppermost part of rivers is simple, but the relative weight of these proportions is unknown unless the different branches are documented with the relative proportion (or indicative number) of fish susceptible to use them.

In the case the upstream migration aims at reproduction, the calculation is quite simple: routes and spawning areas are defined (or can be approximated). The result of calculation is the percentage of reproducers ***potentially*** reaching the spawning area during time range T0-T1 (e.g. 1950-1980). The term “potential” is very important because the aim of the calculation is not to model the number of fishes reaching an area, but if they could reach it. Hence, the descriptors being produced are biased towards the optimistic side. For example, on the upper Loire, the salmon could reach the Villerest dam but does not attempt doing so because no salmon population hatches in this river for more than half a century.

Conversely, the downstream migration computes the proportion of juveniles that reach the sea (or ending recipient), just considering the obstacles issues. The same question of the relative size of source populations is posed to assess unbiased value of the final proportion of fish reaching the final recipient.



Results: ***2100 distribution area***

Salmo salar

➤ **Decrease of presence mainly in the basins around the Bay of Biscay and in the small basins near the English Channel**

🟨 **Stable unsuitable basins**
🟩 **Stable suitable basins**
🟧 **Loss of suitable basins**

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Figure 8: Salmon distribution in Europen catchments.

Source: (copied from slide show by Lassale et coll., see text).

By contrast, if the upstream migration is related to larval or feeding migration, the question is more complex because the target area is not defined: for example eels colonize a large share of catchment and do not attempt to reach those rivers in which their relatives have grown. Precise indicators are to be discussed with experts.

The temporary solution to the dilemma is to carry over two weights, one indicating the passing yield and second indication the population proportion. This second variable is set to 1 by default and documented later.

For the time being, the major jeopardizing issue is the lack of systematic coverage of the European area and provision of historical route extension.

Lassale et coll. (Lassalle, Béguer *et al.*, 2007) identified much contrasted situations regarding the expansion and restriction of basin capabilities *vs.* fish hosting. The current approach, at the “basin” level should be refined to consider the suitability of the truly required areas and fragmentation factors on species distribution. Moreover, quantification of fish possibilities in the more or less suitable basins is expected to improve the current results that already show a largely contrasted situation across Europe.

In the figure the « stable » mention does not imply that the situation is good : salmon is present in the Rhine and virtually absent from the Seine basins.

Application of the route concept to resident fish

Resident fish are “short distance migrators” and explore all routes within a certain area. It seems exceedingly complicated to define as many routes sets as they are fish species. Since the routes for the emblematic migrators are not well documented, it is very unlikely that such data would be readily available for all less famous fish species Moreover, it seemed exceedingly complicated to ;and poorly supported by evidences that obstacle permeability should be considered. However, a same work is or is not obstacle for different fish species, depending on its size (height to simplify, tuned by dam construction type and uses).

It is suggested that each obstacle will be considered as transparent / locking per specie according to its dimensional characteristics. For example a 10cm obstacle is not obstacle for vairone (*Leuciscus souffia*, Risso 1827), whereas a 50 cm is. This figure is different for other species.

The acceptable distances between sets of obstacles are not accurately known; results will be presented as temporal change in distribution of areas per catchment for species and could compare with species observations (this is not part of the module).

Calculations mimicking the real world would be incredibly complex and would require a quantity of data beyond observation and collection capacities. Radical simplifications have to be assumed and considered in the calculation module:

- The assumption that any obstacle makes a barrier seems reasonable, and can be documented per species,
- In a given sub-basin, many species with different passing capabilities exist, hence making it likely that a certain range of obstacle heights (lengths in the case of quality) could affect populations;
- Different species having the same physical capabilities are confined in the same range by the same obstacles.
- A same species may have been observed (population movements) in different areas with time.

The simplest way to assess resident fish fragmentation is therefore to assume a series of virtual fishes each capable of passing a certain class of obstacles and compute the possible domain of linear excursion by passing capacity and secondary to allocate the distribution of excursion lengths to the species supposedly present in the considered areas.

The calculation is then simplified because only the obstacles present during a certain time period are considered and computed. The statistical assessment is carried out over a certain extend of catchments to which different distribution of fish species (present, potential, desirable, etc.) are compared.

Consequently, the calculation of the relevant fragmentation variable is independent of the available documentation of fish populations that are processed at the final stage. It is possible to produce simplified indicators based on just the physical data and secondary refine it with fish population.

5.4.3 Ecological conditions of rivers

Rationales

As mentioned in the section above, changes in ecological conditions (lotic to lentic) are key ecological factor for river. Ideally, the length of the lake created should be populated in the Eldred2 database; this is seldom the case for the large dams and not documented at all for all the non-large dams obtained from different sources.

The lake resulting from a dam is not a flat area, especially is resulting from the impoundment of a long and narrow valley. In the case of non-large dam, true impoundment does not exist and river flow is slowed down on a limited distance. By contrast, assuming a zero discharge at the entry of the impoundment results in a water surface parallel to the equipotential surface of gravity, which projection on the river line equals the shortest river length turned from free-running to slowed or standing water body.

In practice, applying the dam height to the river slope gives a reasonable approximation of the transformed river length which is known through its approximation as projected length. The differences are negligible for the range of slopes that can be met in European rivers.

Assuming that dam creates an impoundment sketched by a triangle with horizontal length P (this is the projected length on the map) height h, the true river length L is the triangle hypotenuse:

Equation 1: $$L^2 = P^2 + h^2$$

Assimilating L to P results in an error by underestimation which value is, simplifying (this is the greatest value).

Equation 2: $(L - P) \div P = E$

The slope k is h/P, hence from Equation 1 and Equation 2, it comes:

Equation 3: $E = \left(\sqrt{P^2(1+k^2)} \middle/ P \right) - 1$ that simplifies in $E = \sqrt{1+k^2} - 1$

The range of slopes recorded during the FAME project (Pont, Hugueny *et al.*, 2006) is 0.01 to 20%, making a maximum error of 2% when taking the projected length instead of the true length. This error is negligible; it reaches half a percent only for slopes greater that 6%, that are seldom reached for most small dams.

The extension of changes along time cannot be assessed in a simple manner because the insufficiency of data:

- ✓ Not all dams are recorded and not all have height data
- ✓ Not all rivers are available in the calculable GIS or the dams cannot be snapped to the GIS

The simplest problem to mitigate is the impossibility of snapping. Computing all slopes within a catchment and comparing to the total height of dams provides acceptable average of slope consumption. This can be done if a homogeneous river GIS (e.g. CCM2) is fitted with elevation data. Applications and statistical tests are currently under realisation for France.

Application

The application of this indicator is part of a task given to ETC/Water in 2007, under the wider assessment of “small water bodies” and has not yet been carried out.

5.5 Other biological targets

For the time being, these targets are not computed by the model. The points mentioned foresee possible extensions which implementation requires full inserting of the model in the spatial platform of the EEA.

5.5.1 *Application to vegetal drifting*

Vegetal drifting issues are computed in the same way as the downstream migration is. Differences are on the sources and end points. The most comparable calculation is the one applying to long distance migratory fish that reach inland lake (and not sea).

5.5.2 *Application to terrestrial fauna*

Obstacles to terrestrial fauna are numerous in river valleys: towns, artificial areas, dams, roads, etc. calculation is in fact identical to calculation considering short distance migratory fish, simply introducing more obstacles that could be analysed separately.

Calculation approach is identical to short distance migratory, with the difference that:

- Different types of obstacles are to be considered,
- Characteristics of obstacle are different. The permeability is depending on the relative size of obstacle vs. the valley width, hence many towns or dams are not obstacles because they are significantly smaller than the width of the valley
- The different obstacles on a same spot (same series of reaches) have additive / worst effect.

The first stage of module development will only make it possible to combine different obstacles to an adjusted tree. No calibration seems possible in a short term; this will be carried out in parallel with terrestrial ecosystems assessments.

5.6 Data sources for obstacles

5.6.1 *Dams as in Eldred2*

The Eldred2 database aims at collecting information on all dams in Europe that matters for the environment to some extend as contributing to river systems fragmentation, sediment trapping or hydrological cycles perturbation.

However, the fact that a dams matters or not is quite difficult to establish. Hence, the current Eldred2 comprises information on:

- All registered “large dams” as defined by Icold (CIGB/ICOLD, 2003),
- All dams from any trustable source. Dams being already integrated under the “large dam” label are flagged as being from several sources.

Before a dam can be identified as “mattering”, the Eldred2 data model considers only if a dam is a potential obstacle to fish, sediment and water. These categories relate to special dam systems and are described in the Eldred2 report (European Environment Agency, 2007).

For example, a dam inside a lake created by a dam is not obstacle to fish or water but can be obstacle to sediment (sediment management at the main dam level is not operative in this case).

Another example is a dam kept and decommissioned, that is no longer obstacle to water (not lake is attached to it) but still locking the valley, hence being obstacle to fish movement.

The indication as potential obstacle aims at removing from calculations all objects that are expressively considered as non relevant under a certain calculation type.

The examples above however reinforce the assumption that the historical development of a dam from its commissioning and after its decommissioning is paramount information for the accurate assessment of river fragmentation.

5.6.2 *Uncertainty attached to dam information*

Obstacle to fish migration is equally resulting from a single impassable obstacle or a series of partly passable obstacles. Moreover, a “large dam” not equipped is certainly impassable since its minimum height is 10 metres above natural ground.

As a result of Icold internal rules, all dams higher than 15 metres are recorded (with exception for Russia, China and the USA and possibly those countries having more than 1,000 dams). Hence not all dams in the range 10 to 15 metres are recorded.

This flexibility in the registration rules makes it possible to have a first bias from the Icold source. Since a dam height between 1 to 2-3 metres can be impassable obstacle to salmon in its upstream migration, there is a huge number of river works that are not registered by Icold.

Indeed, the probability for a bias is all the more bigger when addressing fish issues that sediment trapping and water cycle changes require large volumes that are quite correlated to dam height.

Addressing uncertainty is therefore more important when considering fish issues than when considering the two other classes of fragmentation. This is why considerable efforts were devoted to collect, format and process small dams data in this application.

The complementary data source used is the inventory of dams carried out in the Loire and Brittany catchments jointly by the Loire-Bretagne district authorities (water agency, basin delegation, etc.) and the former Conseil Supérieur de la Pêche (now Onema).

Other districts (namely Seine-Normandie and Rhin-Meuse) have as well carried out such inventories, but the proportion of populated attributes is significantly larger in the Loire-Bretagne data set. In particular, the following items are more frequently populated:

- Date of commissioning / decommissioning (sometimes approximate, but can be guessed),
- Type of work and masonry features,
- Passing codes from in-situ observation
- Work height.

Table 6: Comparative proportion of attributes populated in the 3 small dams available data sets (unpopulated)

District	Total number # / %	With date # / %	With type # / %	With height # / %	With codes # / %
Loire-Bretagne					
Seine-Normandie					
Rhin Meuse					

To be populated later

5.6.3 Other possible data sets

These data sets are mentioned for preparing next developments and assessments;

River quality

River quality is assessed using standardised quality assessment extended using the “quality accounts” module of NOPOLU *Système 2*.

This module allows the use of quality monitoring data stored in the quality management modules (or in external database) to compute quality indexes or to use external quality assessments allocated per river stretch.

Referring to French SEQ (Oudin and Maupas, 1999), the considered target is fish life. The main issue to decide is which length and which quality constitute obstacle.

In the case of migratory fish, a permeability function can be computed from quality and length, for example if the quality index is one class beyond the target, then it is considered 50% permeable per kilometre and quality 2 classes beyond (or “red” class) is considered 10% permeable per kilometre. , indicating that respectively 50% and 10% of fish of the considered group can pass through. Permeability is proportional to the length of bad quality section, one unit length (which is a parameter) constituting one virtual obstacle.

Quality induced delays are documented in the case of nitrogen supersaturation, fatigue is not. It seems that little literature is readily available on this issue.

In the case on resident fish, it is possible to assume that a low permeability is functionally an impervious obstacle to fish.

The current lack of quality descriptors on the linear of rivers has not permitted to check different issues, that pose side problems of calculation because, by contrast with physical obstacles, the water quality obstacles are not located at fix places. This causes no trouble if the quality data is computed with the WQA module, because quality indexes are computed ion the same river reach referential. In this case a series of time depending layers of quality borne obstacle are created by adequate queries applied to the quality results tables.

By contrast, if quality data comes from other sources not referring to the river systems, special preparation should be done prior to assessing the threat of water quality on fish journeying.

Captures

Commercial and recreational capture of fish is a major obstacle to migratory fish. The problem of anadromous and catadromous fish is quite different.

In the case of anadromous fish, adults are the major target for captures. Many regulations apply to commercial fisheries and special regulations (special permits, protection) apply to certain species.

By contrast, the eel glass (eel larvae) populations are subject to intense captures when they reach the estuaries in their upstream migration. Poaching represents a supplementary pressure that is by definition poorly accounted. The decline of eel populations is monitored by the EU Commission that has included the eel in the Data Collection Regulation. In 2005, a specific workshop (Dekker, 2005) compiled all relevant national data and main obstacles to eel migrations.

The way to include captures as obstacles has to be defined.

Other obstacles

A major obstacle class is represented by the dry-out of river reaches under special hydrologic conditions, and more specifically because water abstraction in excess to the available run-off. Two different cases of data availability are possible:

1. the run-off deficit is related to fix works, for example diversion or dam, and the river segments dry-out is considered as a special event attached to physical obstacles,
2. the run-off deficit is related to non-recorded abstractions (for example diffuse pumping for irrigation in a certain catchment) and the probability of having run-off below a threshold is computed from the hydrologic part of the water accounts (quality or resource). In this case the method used for the quality borne obstacle applies, mutatis mutandis.

In both cases, a rule relating the actual run-off to a target should be defined to convert the hydrological descriptor (e.g.: X $m^3.s^{-1}$ during Y days) into a permeability value.

This class of obstacles is defined and inserted only after the hydrological fragmentation has been computed.

6 Results of calibration and validation

6.1 Migratory fish

Several runs were made to adjust the modelling of PDF variables. Based on routes displayed on Figure 7, page 25, two retrospective runs were carried out using the whole dam set and a dm set restricted to large dams only. These runs have the objective of arguing about the possible bias introduced by dam set selection.

Results comparison has to be carried out vs. known fish distribution (potential), hence on a cartographic basis to assess the likelihood of model results on the one hand and statistically to compare both calculations on the other hand. To this end, the indicator developed for SEBI was used. It presents the proportion of fish reaching its targets, the proportion of routes length covered (not weighted by proportion of fish) and the number of final locks. Both calculations were carried out on the period 1700 to 2007 included.

6.1.1 All dams sample

Synthesis

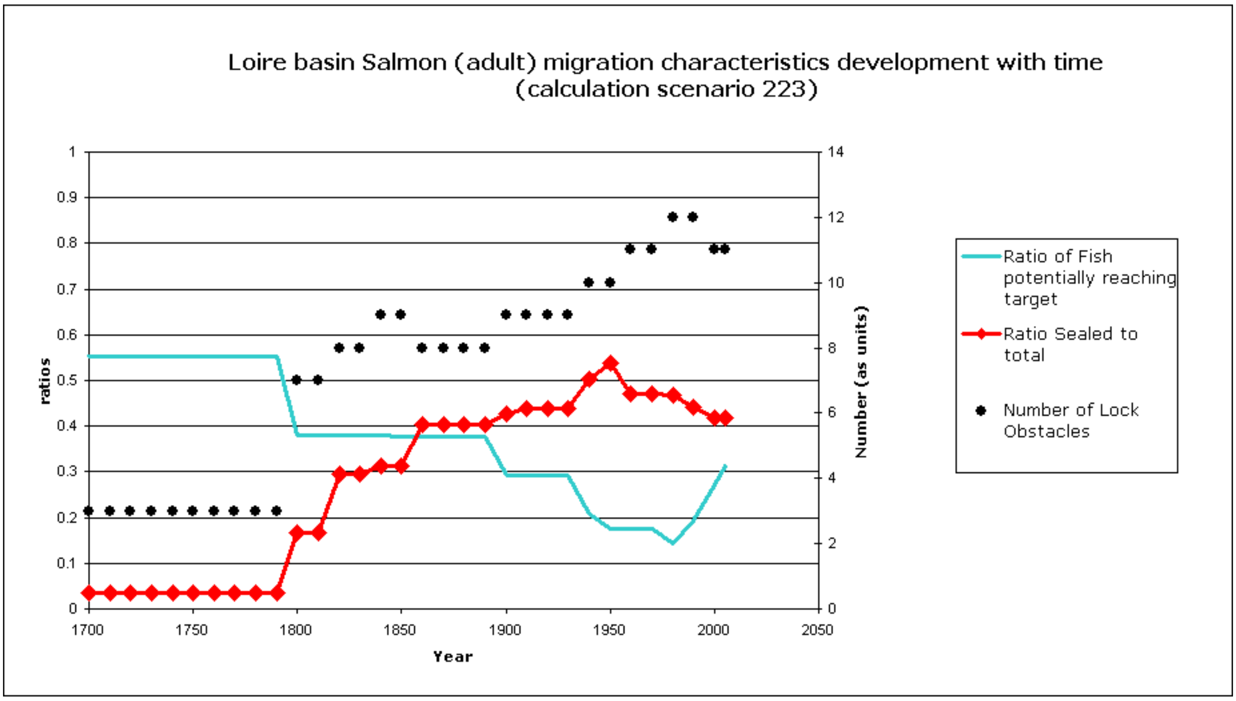


Figure 9: Tentative SEBI graphic indicator for atlantic salmon on the Loire catchment (all dams)

The unchanged values between 1700 and 1790 reflect the patchy commissioning years in this period: all dams “fondé en titre” were assumed existing in 1789 (French revolution starting years).

Six reference years are selected from the graph: 1750 (reference), 1820 (starting industrial damming), 1900, 1950 (peak of fragmentation), 1990, 2005. The corresponding maps are displayed in Figure 10 to Figure 12 included.

All simulations in this run are carried out over the entire set of dams, ranging between 0 cm to several 10 of metres in height.

Selected displays

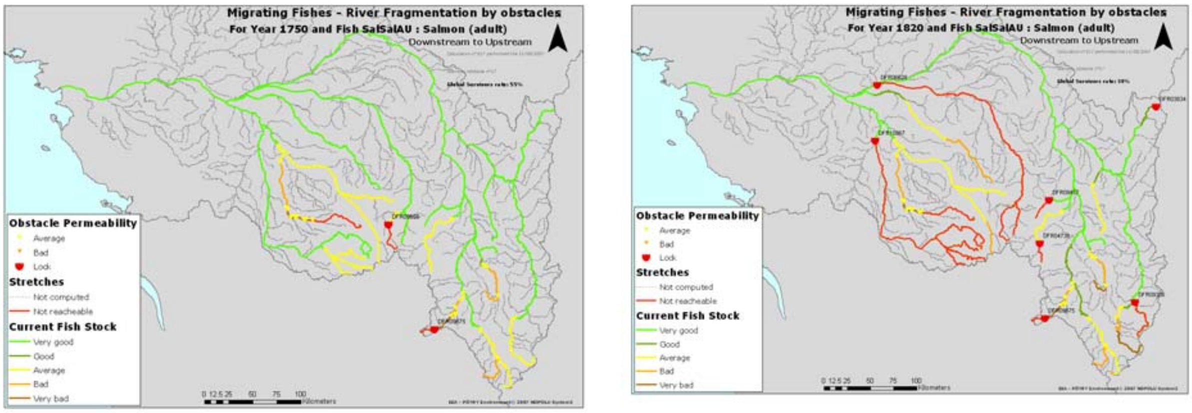


Figure 10: 1750 and 1820. All dams included

Major changes between 1750 and 1820 are in relation with the use of hydraulic power (Vienne river) and navigation sluices on the Cher river. Only the utmost upper Loire becomes threatened. Few single locks are involved

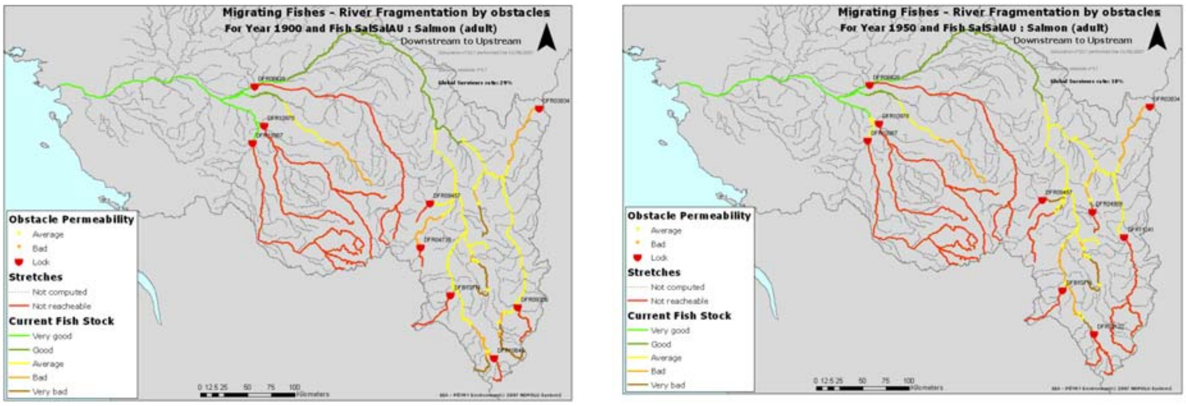


Figure 11: 1900 and 1950. All dams included

During the industrialisation phase, larger dams become operational and spread locking downstream. The main Loire course is still preserved however.

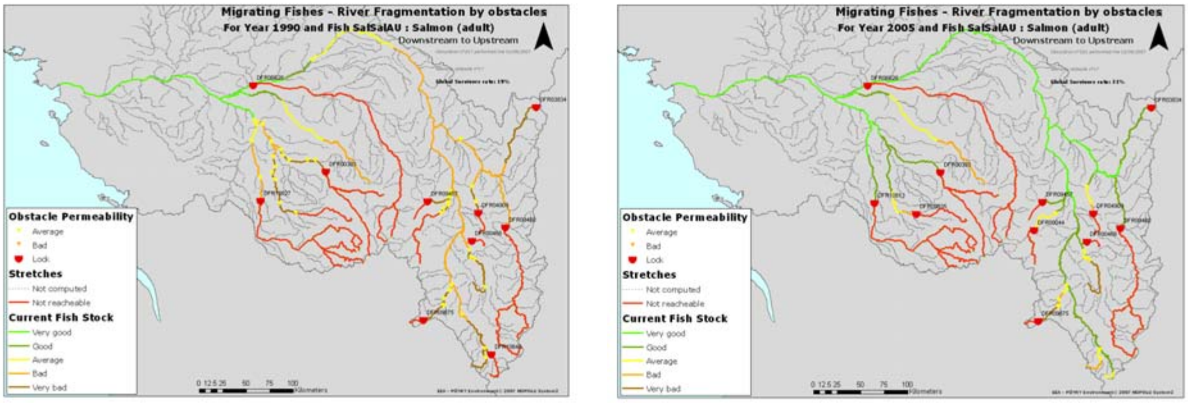


Figure 12: 1990 and 2005. All dams included

The worst situation is at the end of the 1990's, because the main stream of the Loire river has become dammed as well, because nuclear power plants and recreation. None of these works are "large dams".. few places are modifies at the end of the 1990's, reopening many migration axes.

6.1.2 Dams set restricted to large dams

Synthesis

A second run was carried out, with the same scenario fittings, but just considering the large dams, i.e. those registered in the Icold list. The results are reported below. They are dramatically different from the reference situation displayed above.

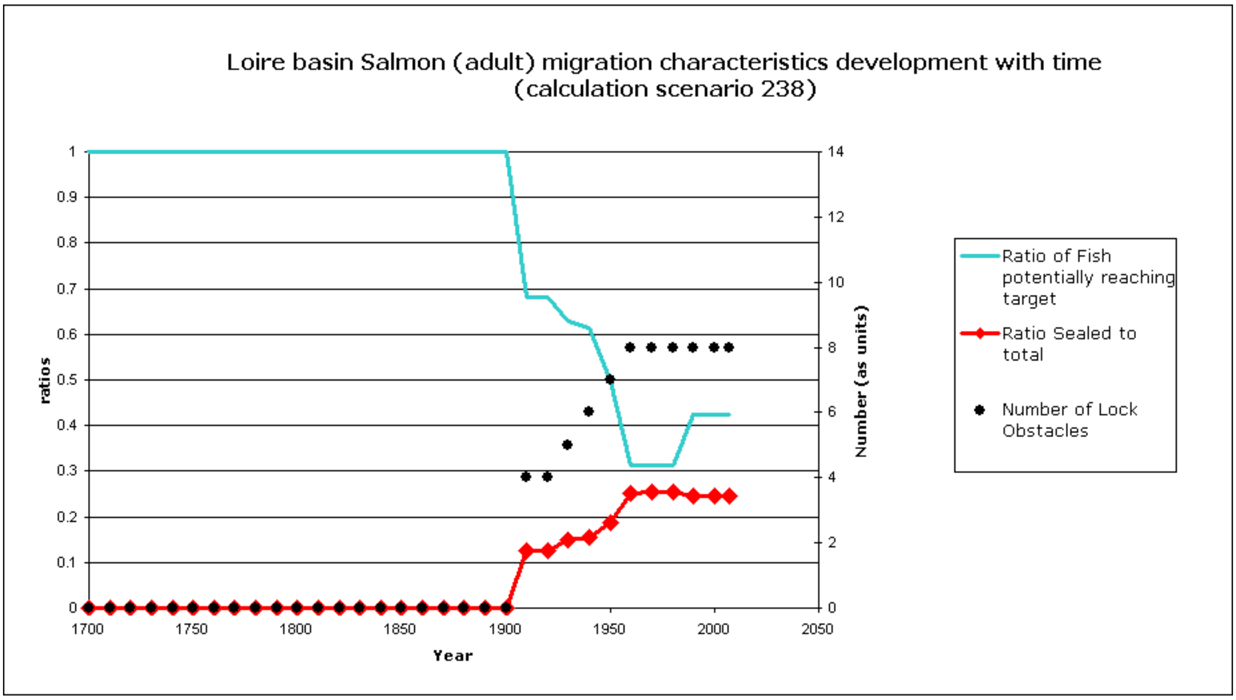


Figure 13: Comparative SEBI graphic indicator for atlantic salmon on the Loire catchment (restricted to large dams, as Icold)

Selected map displays

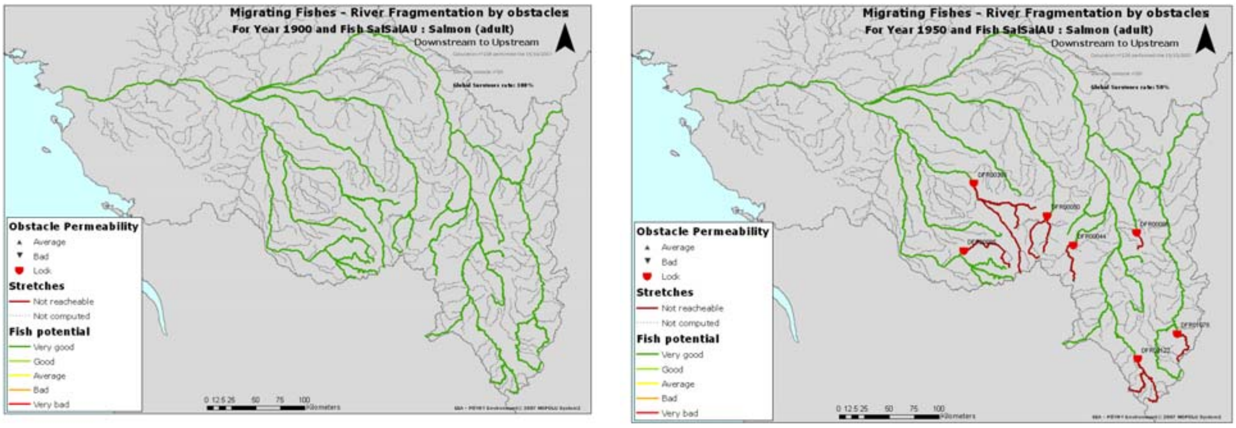


Figure 14: 1900 and 1950. All dams included

The simplified data set does not show any threat in 1900 (and not any before). Some changes appear on the uppermost parts of rivers in 1950.

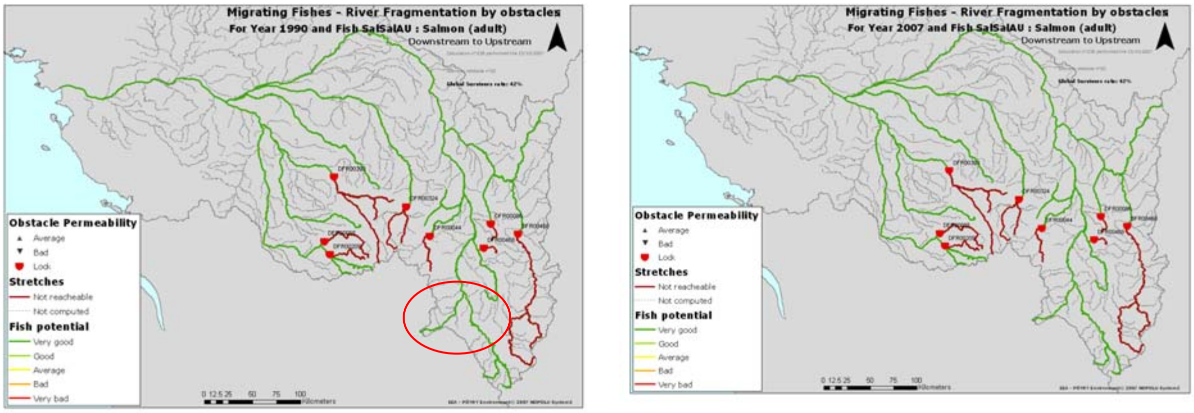
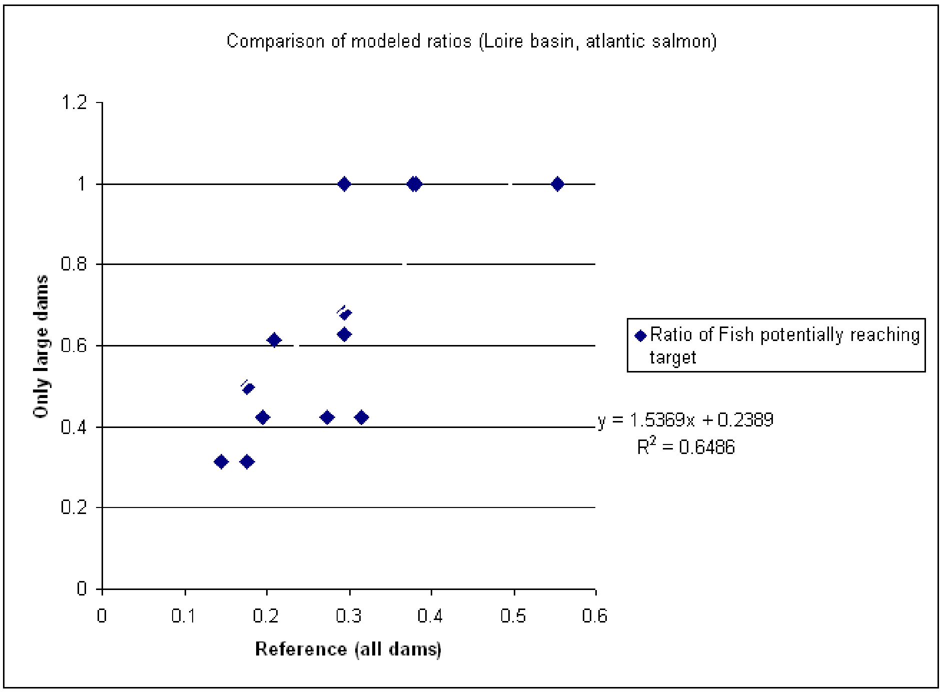


Figure 15: 1990 and 2005. All dams included

Major changes between 1950 and 1990 are on the upper Allier river (red circle in Figure 15, left). This is in relation with the controversial assessment of the Poutès dam, commissioned in 1941, which is considered as lock until it was equipped with fish lift in the late 1980's. the passing possibilities at this dam are reported very differently by different trustable sources. In the model, the CSP source (Conseil Supérieur de la Pêche, 2005) has been used. The P value of 99% resulting from this source is likely being too optimistic.

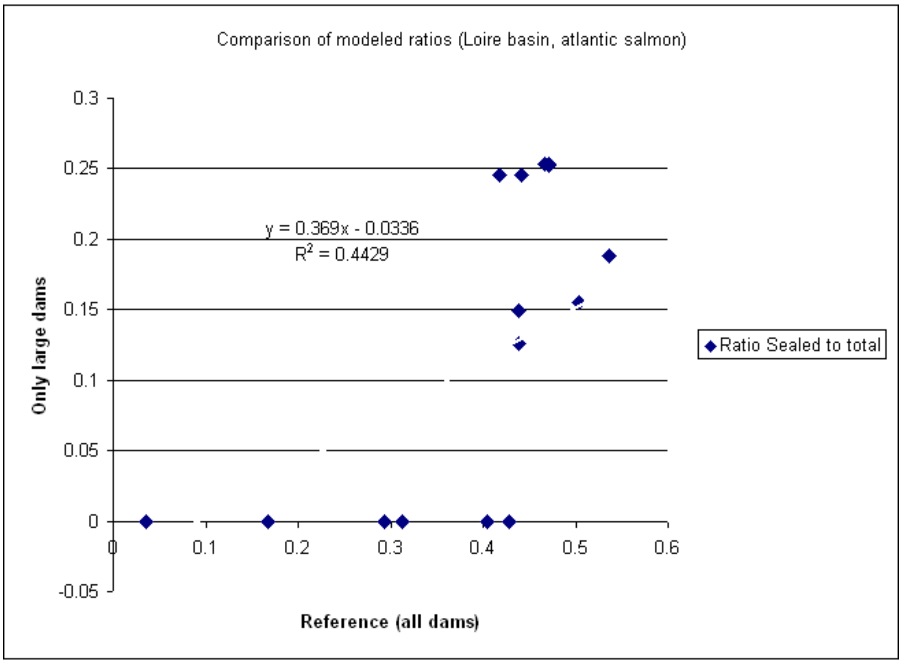
6.1.3 *Comparison and discussion of different dams data sources*

The assessment carried out with the complete set of dams is not certainly depicting the true field situation, for reasons in relation with the model itself and uncertainty on data as well. However, this is likely to be a reference assessment, since all dams potentially mattering are processed. By contrast, the calculation involving a limited set of dams presents a possibly more optimistic situation. The question raised is *"does an assessment carried out with a biased set of dams present an acceptable picture of the river fragmentation?"*



Comments: Fish number ratios are substantially overestimated when considering only large dams. In good situation, the scenario "large dams" does not show any impact, whereas it overestimates the number of fish by a twofold factor. The correlation indicator is spurious because the small number of observations, hence the prediction capability of the regression is close to nil.

Figure 16: Comparison of number of fish potentially reaching their targets, as initial population numbers ratio.



Comments: the relative sealed route length is very poorly predicted when using only the large dams subset: as suggested by the maps, no large dam on the salmon migration routes is documented before 1900. Hence the 18th and 19th centuries, that are the very start of the reduction in migration possibilities for salmon are not accurately modelled. Where the potential population ration was overestimated by a twofold factor, sealed route length is not estimated at all. The apparently acceptable correlation factor is purely the result of many data pairs 0, x making a spurious trend on the data set. .

Figure 17: Comparison of the relative sealed river route length

The simple assessment unfortunately demonstrates the unsuitability of restricted dam data set in the assessment of river fragmentation, in the case of migratory fish and jeopardizes the production of relevant indicator. The case of salmon is all the more demonstrative that it is the only fish having large passing capabilities. In the case of salmon, the smaller dams have little or no effect, which is not the case for the twaite shad for example.

The comparative assessment on the relative capacities of complete and filtered data sets should not be used to conclude on the lack of threat related to the presence of large dams. In fact, the threat is in relation with both the relative place of dam on the river system and the dates when this or that work was set. In the case of the pilot work carried out on the Loire catchment, most baseline threats resulted from numerous partly passable or impassable small dams commissioned early in time (e.g. first half of the 19th century). Large dams were the set-up in rivers from which salmon had been partly or fully eradicated for decades.

This finding has important political consequence: the present locks are not necessarily the cause of fish disappearing, however their removal or equipment would not help restoring fish in most cases. This assumption could be considered as “stating the obvious” for experts but, considered from the point of view of message that could be derived from indicator production is has to be understood as a strong warning against the risk of misleading information.

6.1.4 Improvements and follow-up

Dams data sets

The source of dam information seems to be the most critical issue: incomplete documentation is likely to lead to the production of spurious indicators. Complementary calculations could be carried out in British Isles, as soon as the river GIS is ready because all smaller dams that matter are already collected and in the data base.

A comparable exercise could be carried out in any basin in which sufficient data is available. This is a crucial issue for the next moths to define the adequate data flow.

Fish extension

Mapping fish extension is prerequisite to supplementary calculations.

Comparative data

Comparing model results and observations can be done for the past years only. Suggestions on the best way to carry this out, considering the variability in observations, are the welcome. The FAME project would probably substantially contribute to this issue.

6.2 Resident fish

6.2.1 Modelled approach

Resident fish is impacted by the range of rivers stretches in which is may freely circulate. The calculation of this descriptor involves detailed river GIS and all dams being snapped: resident fish are often blocked by small dams.

The normal indicator is the calculation of all extend of river stretches between a set of dams having a certain passing threshold, in relation with fish capacity. A sample calculation has been carried out considering a generic fish having a passing capacity of 50cm, applied to all rivers of the Loire catchment dataset. However, the settings had not been done correctly, hence the value of results are not correct.

Calculations are extremely long (the same set based on 3 centuries and a time step of 10 years could not be carried out in a whole week-end, the computed years range only between 1700 and 1950 included) and algorithm optimisation is under assessment.

This method provides the true river length between set of dams, as displayed in Figure 4, page 17.

6.2.2 Possible analysis of results

The model provides the distribution of lengths between two impassable obstacles. The values, in the calculated years range between 100 metres to more than 10,000 kilometres, depending on the year. No satisfactory solution has been found up tot now to:

- Analyse results,
- Display map of results

Reasons are theoretical and practical.

An unfragmented river system comprises a single reach which length is the total river system length. In the analysed case of the Loire catchment, the total length is 17,910 km.

At the opposite end, a totally fragmented system, e.g. at the hectometre resolution, would comprise 179,100 segments of 100 metres. Any distribution of lengths for any number of items expresses the actual distribution a certain year.

For the time being, no simple statistical representation has been found: data distribution does not fit classical probability laws. The closest in shape could be the Weibull law because it normally adjusts to frequent values close to zero and very rare high values, provided the shape factor is less or equal than 1. A second candidate could be the log-normal law, but it normally comprises a peak between frequency 0 of smallest values and the average.

Both adjustments were unsatisfactory and could not be statistically accepted, by contrast in all cases (including selection of range, etc.) the hypothesis of adjustment had to be rejected with 99% certainty.

Until new assessments methods are found, the simplest representation is therefore a graph expressing the development with time of percentage or river length belonging to a certain range of length.

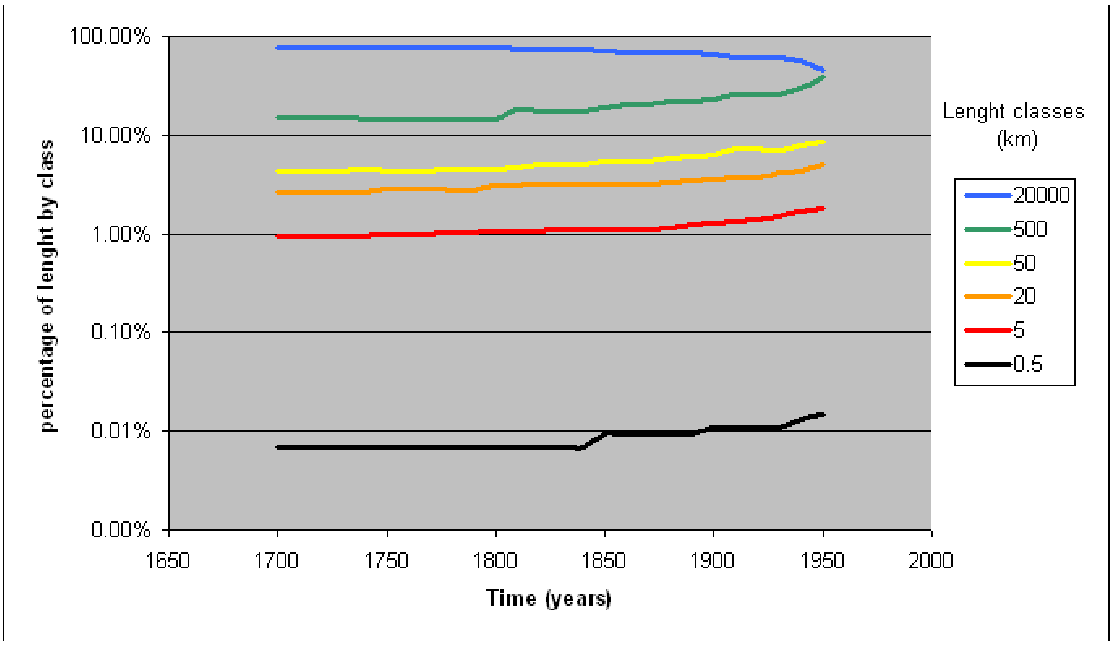


Figure 18: Change in percentage of river length. Simulation 235 (generic fish 50cm). Loire basin. Values likely to be factually inaccurate and used for demonstration.

The graphic in Figure 18 shows the sharp change in percentage of total river length in smaller values at the expense of the longest continuous system, extending over more that 13,000 km eventually reduced to 7,000 at the end of the calculation period.

Cartographic display is possible but requires precisely defining what should be represented and how to populate the cartographic tables with this information.

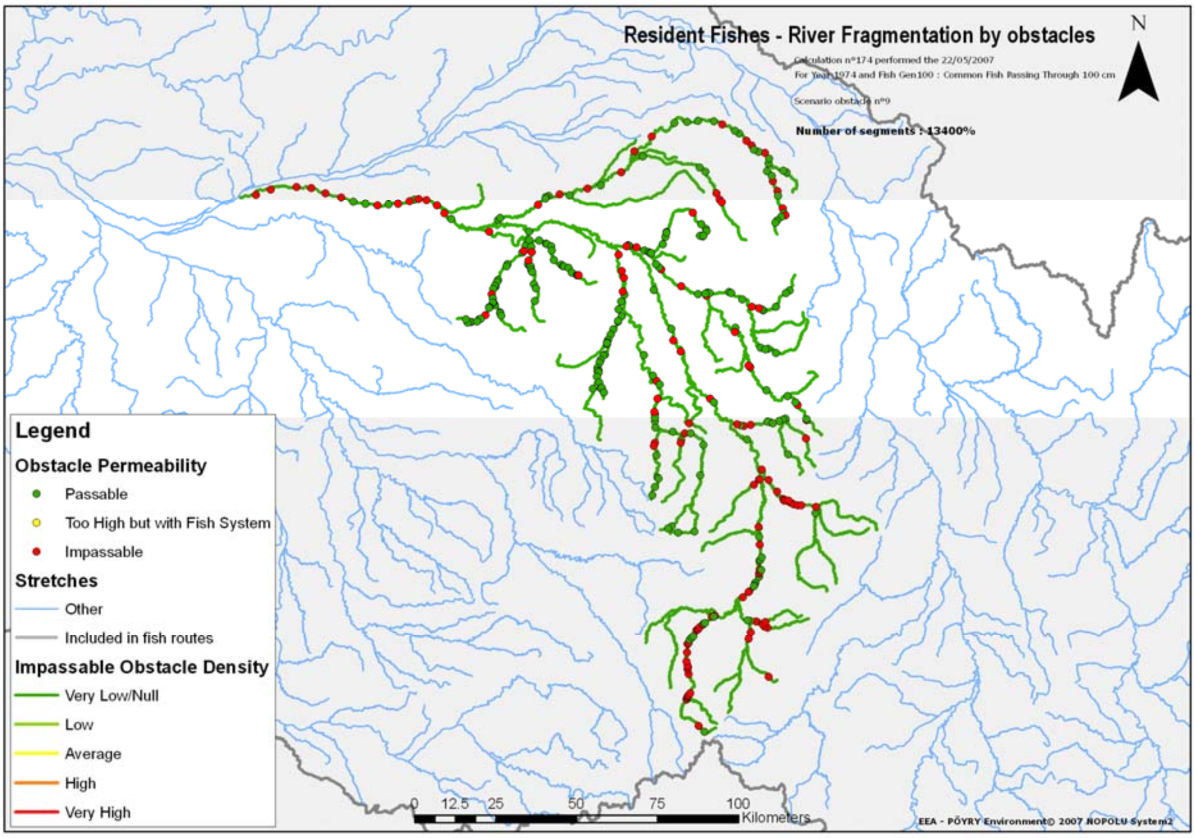


Figure 19: Sample map display of resident fish fragmentation. Model checking calculations

No solution has been found for the time being. The reasons are:

- The cumulated length aggregated in Figure 18 extends on several river reaches that are the units that can be displayed. However it is not possible to identify all the reaches belonging to the same set of continuous reaches prior to making a map. This would however be the most satisfactory solution, and its feasibility analysed,
- A density of obstacles is being computed, but the reference value for the density calculation is not satisfactory (should it be the “river”?, the reaches between two confluences?)

An example map is given, just displaying the dams that made obstacles during a certain calculation.

6.2.3 Improvements and follow-up

Restrictions in the living space for resident fish are directly depending on the knowledge of small dams and their major characteristics, of which commissioning date and height are essential. These data are not collected everywhere and supplementary analysis on the distribution of documented dams on the one hand and possible thresholds in data collection on the other hand are critical issues .

A systematic comparison between fish population and simulations on fragmentation would help defining adequate analysis thresholds. The values set to make Figure 18 for example are not necessarily the most accurate.

Similarly, there is no relevant indicator depicting resident fish fragmentation, and developments are expected on this issue.

6.3 Changes in river habitats

The project in charge of analysing this issue has not advanced enough to be reported.

7 Conclusions

Conclusions shall be drafted after the workshop held in Paris 23 October 2007

8 References and Glossary

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