Report of FP6-project FP6-022488 Restoration of the European eel population; pilot studies for a scientific framework in support of sustainable management.

Slime

Study Leading to Informed Management of Eels

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Policy-oriented research, Scientific support to policies - SSP
Integrating and Strengthening the European Research Area

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Dissemination level	Public

Table of Contents

This report presents the outcome of FP6-project 022448 SLIME in three layers:

- A one-page Abstract on the next page;
- A twenty-page report, describing the main features in non-technical language;
- A CD and web-site (www.DiadFish.org/English/SLIME), providing detailed descriptions of mathematical models, case studies, model comparisons and case study evaluations.

During the Project Workshop in Parma, a short visit to the XVth century Castello di Torrechiara (Comune di Langhirano) revealed numerous wall paintings, on some of which eels were depicted. The capital S on the front cover is derived from one of these.

Abstract

Dekker W., Pawson M., Walker A., Rosell R., Evans D., Briand C., Castelnaud G., Lambert P., Beaulaton L., Åström M., Wickström H., Poole R., McCarthy T.K., Blaszkowski M., de Leo G. and Bevacqua D. 2006 Report of FP6-project FP6-022488, Restoration of the European eel population; pilot studies for a scientific framework in support of sustainable management: SLIME. 19 pp. + CD, http://www.DiadFish.org/English/SLIME.

The eel stock in Europe is in rapid decline, and both EIFAC/ICES and the European Commission have advised urgent management action to protect and restore the stock. Given the scattered distribution of the eel in inland and coastal waters across Europe, sustainable management and restoration of the common spawning stock in the Sargasso Sea can only be achieved through local management measures, integrated on a European scale. These measures must address all continental life stages: glass eel (young, unpigmented eel, recruiting from the sea into continental waters), yellow eel (resident growth stage) and silver eel (emigrating spawners), with the specific objective of overall protection of the spawning stock.

Individual river basins have been identified as the primary management units for implementation of the Water Framework Directive. While protective measures for eel must also be river basin-specific, a common approach and an equitable balance between countries are required. Joint development of targets and tools will provide a cost-effective and consistent approach to management of these widespread fish. The EIFAC/ICES Working Group on Eels (ICES 2005), therefore, suggested an initiative to coordinate ongoing national development of models, and to stimulate further development by applying them to real data. To this end, the SLIME project proposal was submitted to the EC's Sixth Framework Programme. The current report presents the outcome of this short project. The project acronym is SLIME, Study Leading to Informed Management of Eels.

The aims of this project were to test quantitative approaches to evaluate the status of national eel stocks at a river basin level, to derive reference points for sustainability, and to model the potential effect of legal and technical measures aimed at stock recovery. A total of six different models were tested, using 10 case study data sets from all over Europe, dealing with fisheries for glass eels and for yellow/silver eels, and covering habitat quantity, quality, productivity and connectivity issues, recruitment variation, and other aspects of the biology of eels and anthropogenic impacts on their populations.

The SLIME project was built upon the results of earlier national initiatives to develop modelling tools and collect field data. Implementation of the models will require validation and extension of these tools, application to specific cases, and integration into comprehensive Eel Management Plans.

This project report presents a succinct description of the models, case studies, and their applications, and discusses strengths, weaknesses and options for further developments. The project CD and web-site (www.DiadFish.org/English/SLIME) provide detailed reports on each model and case study, as well as presenting a more detailed comparison of models and their applications.

Photo: Håkan Wickström

Partners in the SLIME project

The SLIME-workshop
was organised at the
University of Parma:

Dear Reader,

We offer, with some reservations,
This product of deliberations,
Forged in toasting Parma heat:
Some models, mostly incomplete.
Apply them to your population
Of eel, for your information,
To help you save the eel in time!

Yours sincerely,
Partners in SLIME.

1 Introduction

The European eel stock is in decline in almost the whole of its distribution area. Overall, recruitment of glass eels from the Atlantic Ocean fell in the 1980s to about 10% of former levels, followed by a further decline to 1-5% since 2000 (Figure 2). Fishery catches have gradually declined over the second half of the 20th century, down to less than half the former level. The International Council for the Exploration of the Sea (ICES) considers that the stock is outside safe biological limits and that current fisheries are not sustainable. Therefore, ICES (1999-2006) advised that an international stock protection and recovery plan should be developed, and that fisheries and other anthropogenic impacts be restricted to as close to zero as possible until such a plan has been implemented. The European Commission initiated the development of a Community Action Plan for the management of the European eel (COM 2003, 573; detailed in COM 2005, 472), with the objective to permit the escapement to the sea of at least 40% of the biomass of silver eel relative to the potential escapement in the absence of human activities affecting the fishing area or the stock.

The essentially local nature of eel populations means that responsibility for the attainment of this objective largely resides with national governments, with individual river basins as the primary management units. The challenge for the European Community, however, is to design a management system that ensures that local measures produce equitable and consistent results across river basins and countries. Because protective measures for eel must be river basin-specific, joint development of targets and analytical tools will provide a cost-effective and consistent approach to conservation of this widespread species.

The global objectives of protection and rebuilding the eel stock must be translated into actual management targets, for management of fisheries as well as for habitat restoration, at a local or regional level. It is highly unlikely that the status of a local stock can be assessed in all waters in Europe where eels are found. Pragmatic approaches and the use of models are required.

The EIFAC/ICES Working Group on Eels (ICES 2005), therefore, proposed an initiative to coordinate and stimulate ongoing national development of models by application to real data, available at other places. It was hoped that coordination, standardisation and comprehensiveness will lead to a flexible, cost-effective, adequate and mutually acceptable approach throughout the eel's distribution area.

To this end, the SLIME project proposal was submitted to the EC's Sixth Framework Programme by a consortium of scientists. SLIME essentially focused on development of models with the aim to develop quantitative approaches to evaluate the status of national eel stocks at a river basin level, to derive reference points for sustainability, and to model the potential effect of legal and technical measures aimed at stock recovery.

2 Overview of this report

The SLIME-project brought together modellers and eel researchers from all over Europe, to apply to their models to others' data, to compare approaches and results, and to promote further ideas. This report presents the major features and outcomes of our work. More detailed analyses of comparisons and evaluations of each of the models and each of the case studies used in this project are presented on the CD and web-site (www.DiadFish.org/English/SLIME) of this project. The CD and web-site open with a page of the same structure as the main report, but providing access to separate documents that can be read as stand-alone texts. In this way, we hope to serve both generalists and specialists.

This report will introduce the reader to the extraordinary biology of the eel; will sketch the background, the objectives and the framework within which we developed our models; will present the outline of the models, with practical examples; will evaluate pros and cons of different modelling approaches in relation to their purpose; and will explore consequences of our work for the ongoing process of monitoring eel populations and providing scientific advice for management. The report ends with recommendations for further developments, and a list of project contributors.

3 Eel life cycle and biology

Although the eel's life cycle is incompletely known, reproduction must take place somewhere in the Atlantic Ocean, presumably in the Sargasso Sea area, where the smallest larvae have been found. Neither spawning adults nor eggs have ever been observed in the wild. Larvae (*Leptocephali*) of progressively larger size are found as one moves from the Sargasso Sea to European continental shelf waters. At the shelf edge, the laterally flattened *Leptocephalus* transforms into a rounded glass eel, which has the same shape as an adult eel, but is unpigmented. Glass eel migrate into coastal waters, estuaries, rivers and eventually into lakes and streams. Following immigration into continental waters, the prolonged yellow eel stage begins, which lasts for up to 20 or more years. During this stage, the eels may occupy fresh water or inshore marine and estuarine areas, where they grow, feeding on insects, worms, molluscs, crustaceans and fish, but – contrary to popular belief – not carrion. Sex differentiation occurs when the eels are partly grown, though the mechanism is not fully understood and probably depends on local stock density. At the end of the continental growing period, the eels mature and return from the coast to the Atlantic Ocean; this stage is known as the silver eel. Female silver eels grow larger and may be twice as old as males. The biology of the returning silver eel in ocean waters is completely unknown. Consequently, the target for restoration of the spawning stock is formulated in terms of the escapement of silver eels from continental waters towards the ocean.

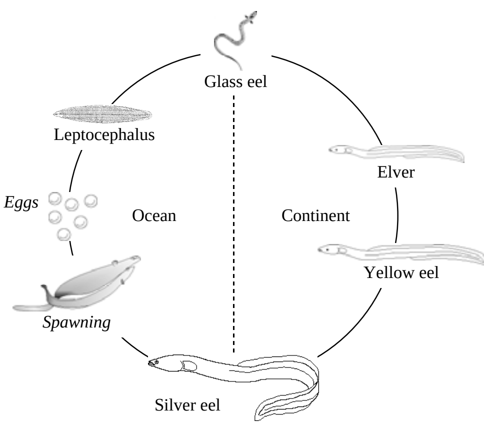


Figure 1. The life cycle of the European eel. The names of the major life stages are indicated; spawning and eggs have never been observed in the wild and are therefore only tentatively included. (Diagram: Willem Dekker).

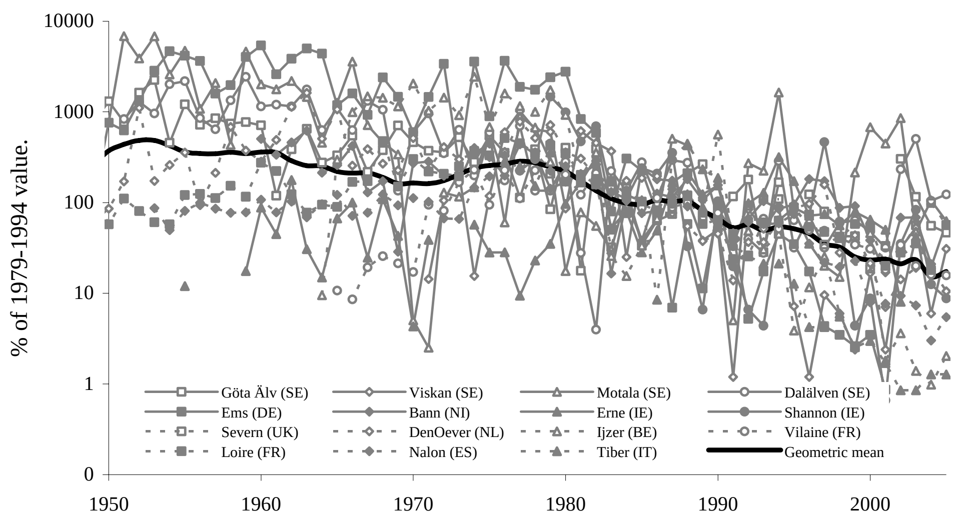


Figure 2. Time series of recruitment monitoring in European rivers. Each series has been scaled to the 1979-1994 average. Note the logarithmic vertical axis. (Source: ICES 2006).

4 Management, models and monitoring

Performing the art of mathematical modelling is not a goal in itself, but a means to provide scientific advice to support the development of management plans. For any fish stock, a model is required to evaluate local stock status in relation to reference points for sustainability. The international judgement that the eel stock is depleted, and its fishery is unsustainable, is predominantly based on the strongly declining trends in recruitment indices. At the local or regional scale, eel stock monitoring series and information on anthropogenic impacts are often lacking. In these situations, models can complement, although not completely substitute for, an analytical assessment of the stock. With a general knowledge of eel biology, strengthened with available data, a model may yield an initial assessment of the status of the stock in relation to sustainability targets. To provide advice on sustainable management, we need to know the pressures that anthropogenic activities generate on the stock; whether these conflict with the sustainability targets set in the recovery plan; whether pragmatic reference points for local management can be derived; and what quantitative effect the management options available for remedial action will have. This was the main focus of this project. Following implementation of protective measures, focus will shift towards monitoring and post-evaluation of the net effect of the management measures taken. Post-evaluation will require refinement of the current models and undoubtedly need its own models and tools. At this moment, only one of our models addresses this latter issue.

5 SLIME collates national initiatives

The precarious state of the eel stock has given rise to several national/regional initiatives to document local eel stocks and to develop modelling tools. The SLIME-project did not initiate these developments, but collated the results from separate initiatives and compared and contrasted them at the international level. We gratefully acknowledge that the data and models were made available to the project, but recognise that their publication within this report must not breach intellectual property rights, nor interfere with original intentions and applications. Consequently, only limited technical detail is presented here. Similarly, this report should not be considered as providing case-specific robust analyses or scientific advice.

Though eight partners were officially involved in the SLIME-project, to provided a template for further developments as and when required for the compilation of national Eel Management Plans, we were supported by a wider group of experts who are identified at the end of this report.

6 Outline of SLIME case studies

The aim of the SLIME project was to coordinate and stimulate further development of national eel-related models by application to real data for case studies. These are briefly described in this section; a more detailed description of each of the case studies is found on the project-CD and web-site (www.DiadFish.org/English/SLIME). The case studies are: 6.1 the Swedish West (mainly yellow eel) and East Coast (mainly silver eel) fisheries; 6.2 Lake IJsselmeer yellow eel fishery in the Netherlands; 6.3 Lough Neagh yellow and silver eel fisheries in Northern Ireland; 6.4 the Burrishoole catchment, an unexploited river in Western Ireland; 6.5 the Shannon catchment in South-western Ireland, with small-scale test fishing; 6.6 the Severn in the South of Wales, with an intense glass eel fishery; 6.7 the Piddle and Frome catchment in Southern England, based on detailed stock surveys; 6.8 the glass eel fishery in the

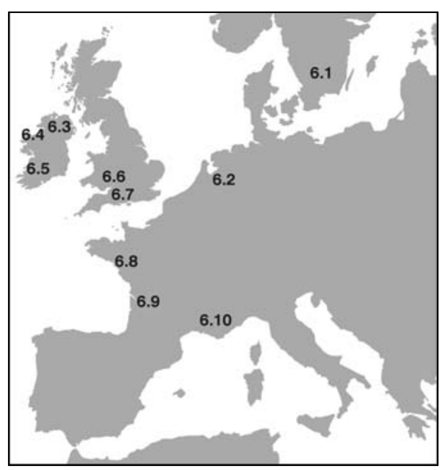


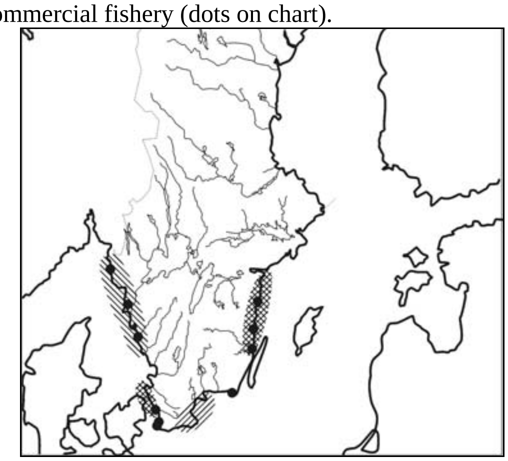
Figure 3. The location of the case studies, and their corresponding paragraph numbers (below).

Vilaine estuary, southern Brittany; 6.9 the Garonne catchment in South-western France, having glass eel and yellow eel fisheries, and major dams; and 6.10 the Camargue, in Southern France, showing the typical Mediterranean lagoon fisheries. Each case study chart shows the rivers and tributaries for which data are available, major conurbations, dams (**l**) and fisheries (hatched areas).

6.1 The Swedish West- and East Coast.

The Baltic Sea (East Coast) area is characterised as a low salinity (ca 6-7 PSU) archipelago with an important eel fishery using fyke nets and pound nets for both yellow and silver eels. Along the more saline (ca 20 PSU) Kattegat-Skagerrak Coast (West Coast) the eel fishery is dominated by a fyke net and pot (baited) fishery for yellow eels. The data used for modelling are derived from investigations related to the environmental impact from nuclear cooling water and from sampling programmes for the commercial fishery (dots on chart).

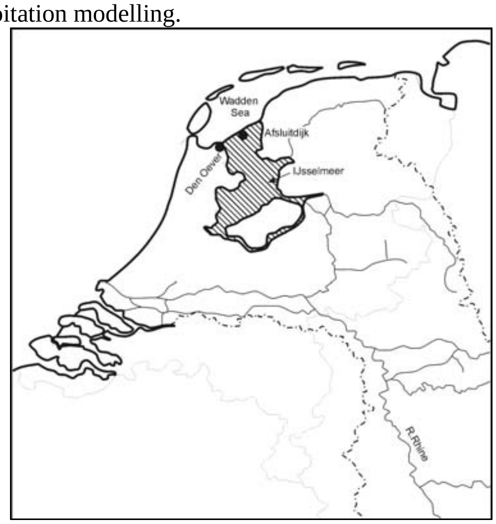
Figure 4. A yellow eel fisherman attending his fykes in a typical Swedish West Coast habitat.
(Photo: Björn Fagerholm *Institute of Coastal Research, Sweden)*



6.2 Lake IJsselmeer

Lake IJsselmeer (now 1820 km^2) is a former estuary of the River Rhine, reclaimed from the Wadden Sea in 1932. Polders have since reclaimed half of the original surface area. The lake is now fresh and eutrophic, and has an average depth of 2-4 m. Following the reclamation, an intense eel fishery developed using a range of gears, and detailed sampling of recruitment, stock and fishery has been carried out. The wealth of data, and the extreme overexploitation, makes Lake IJsselmeer primarily a case for exploitation modelling.

Figure 5. A fisherman attending to his fyke nets, set against the dike. Insets: aerial view of a dike subdividing the lake (note the difference in turbidities); the sluices to the Wadden Sea, where glass eel recruitment is monitored.

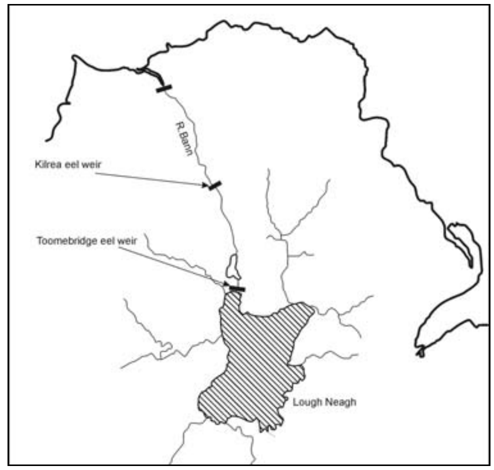


Lake IJsselmeer is a former estuary, reclaimed from the Wadden Sea in 1932. It belongs to the River Rhine basin. Polders have reclaimed half the original surface area.
(Photos: Jan van Willigen; left inset unknown)

6.3 Lough Neagh

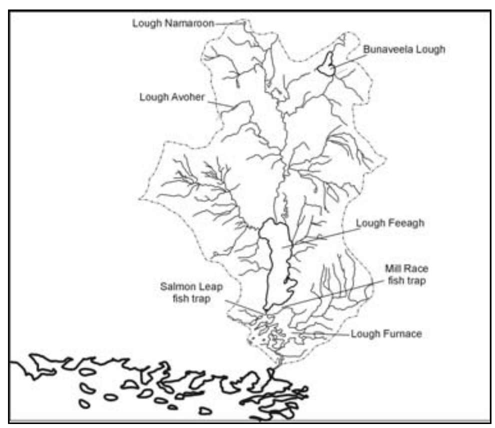
Lough Neagh, Northern Ireland, is the largest lake in Britain and Ireland, covering 400 km^2 at a mean depth of 9m. Its hypertrophic waters flow northward to the Atlantic Ocean through the River Bann. Since 1960 it has supported Europe's largest commercial eel fishery, for which records of recruitment and catch have been maintained and it has been the subject of several scientific studies. This wealth of data makes L.Neagh an ideal case study for exploitation modelling.

Figure 6. View on Lough Neagh; insets: long line fishing, grading the catch at Toomebridge. (Photo: Robert Russell)



6.4 The Burrishoole Catchment

The Burrishoole catchment, in the west of Ireland, consists of rivers and lakes with relatively acid waters. The catchment has never been commercially fished and there are no barriers or turbines. The eels have been intensively studied since the mid-1950s; total silver eel escapement from freshwater was counted since 1970; and an intensive baseline survey was undertaken in 1987-88. The detailed nature of the Burrishoole data makes it suitable for model calibration and validation.

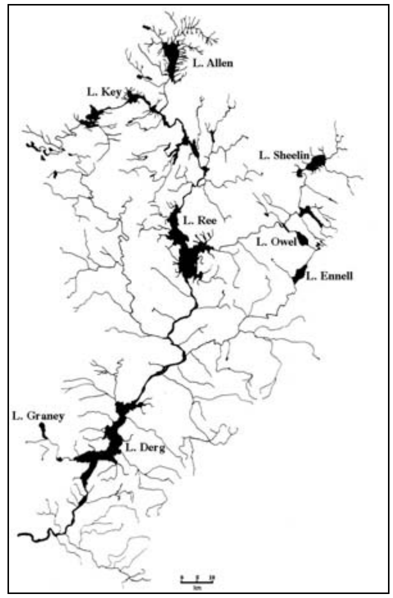


← **Figure 7.** An aerial view of the Burrishoole catchment, looking north over the tidal Lough Furnace, in the foreground, and the freshwater Lough Feeagh: inset shows the silver eel downstream trap at the "Salmon Leap".
(Photo: Martin O'Grady, Central Fisheries Board;
trap inset: Gerard Rogan, Marine Institute.)

6.5 Shannon

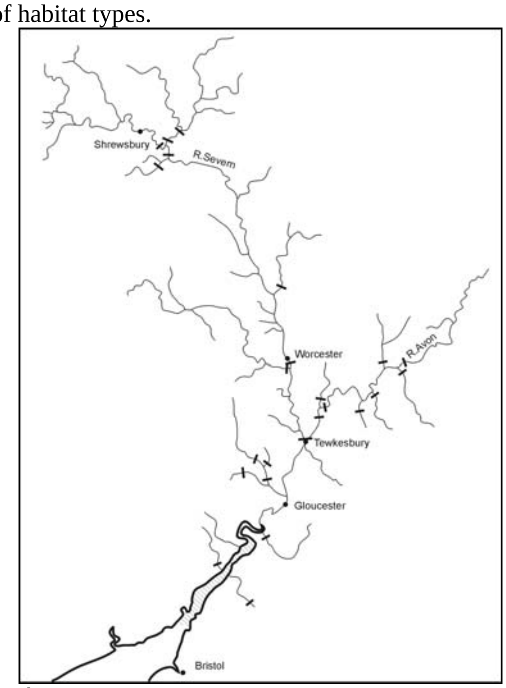
The River Shannon (mean annual discharge 186 m^3 sec^{-1}; drainage area 11,700km^2) is Irelands largest river. Its eel fisheries are owned and managed by the Electricity Supply Board, who use the river for hydropower generation. Historical data on commercial catches, records of stocking programmes and results of extensive scientific surveys of eel populations, make this a good example of a managed eel fishery that is affected by river regulation and by obstacles to natural eel migratory patterns.

Figure 8. Top: Lough Derg (Shannon); bottom: weir fishing at Killaloe bridge.
(Photos: Marcin Blaszkowski and Paula Cullen)



6.6 River Severn

The River Severn flows 350 km through a predominantly rural but also urban catchment to the Bristol Channel, which attracts strong glass eel recruitment and supports a major fishery. Eel are distributed throughout, except in streams in the Cambrian mountains and urban areas, but there are many barriers to migration. Estimates of the glass eel fishery annual effort/catch data are available annually, and yellow eel distribution and population data are available for the early 1980s, late 1990s and annually since 2002. The Severn case study is suitable for testing models of yellow eel production from a variety of habitat types.

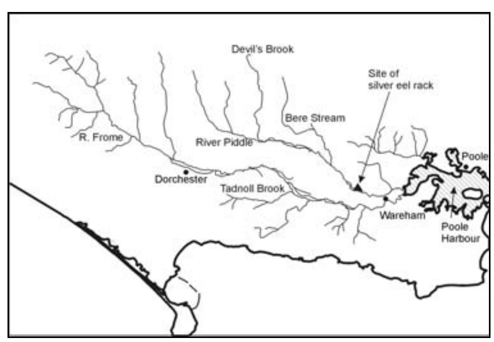


← **Figure 9.** Three views on the River Severn.
(Photo Upper Severn: Kings College, London - others: unknown)

6.7 Rivers Piddle and Frome

The Rivers Piddle and Frome are short (30 and 48 km long) chalk stream rivers in south-west England, both of which drain into Poole Harbour. Catchment land usage is predominately agricultural and water quality is very good. There is limited silver eel exploitation on the Piddle and a yellow eel fishery in Poole Harbour. Comprehensive eel data are available from 1999 onwards and silver catches are available for both rivers in 2003-2004. This allows investigating yellow eel production in a chalk stream habitat and has the potential to provide data for calibrating models silver eel output.

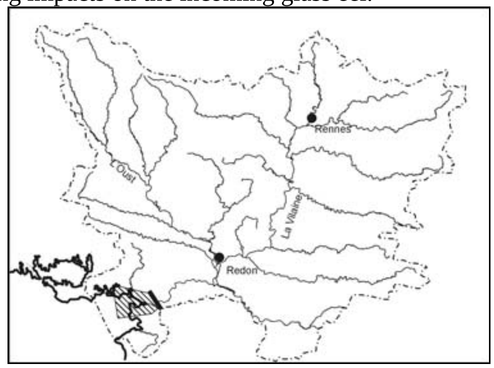
Figure 10. Survey sites on the River Piddle
(Photos: Kings College, London)



6.8 Vilaine

The Vilaine catchment (10,4000 km²; southern Brittany, NW France) has an intensive glass eel fishery located just below the estuarine dam. A time series of glass eel recruitment, point stock estimates by mark-recapture and samples for pigment stage are available. Catch and effort data are collected from logbook surveys, commercial surveys and a boat census during the season. This makes the Vilaine a case for modelling impacts on the incoming glass eel.

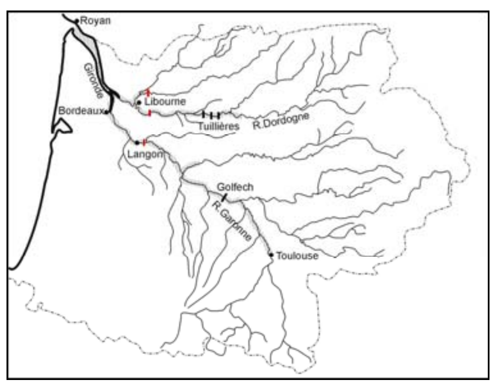
Figure 11. Aerial views of the downstream Vilaine (during a flood period in the Redon marsh), the Arzal Dam and the fishery. (Photo: Cedric Briand)



6.9 Garonne

The Garonne river basin (81000 km^2) in south-west France, comprises the brackish Gironde estuary (635 km^2 surface), and the rivers Garonne (57,000 km^2) and Dordogne (24,000 km^2), both with major dams. Glass eel fishing is concentrated in the tidal area; yellow eel fishing is found throughout the basin. Catch and effort are regularly sampled and recorded. Independent stock surveys have been conducted in the estuary since 1978; and in fresh water since 1975. The fully documented fisheries on all life stages in a well documented river network make the Garonne a case for comprehensive modelling of the eel stock.

Figure 12. A *pibalour*, the large push net used in the estuary of the Garonne for glass eels.
(Photo: Laurent Beaulaton)

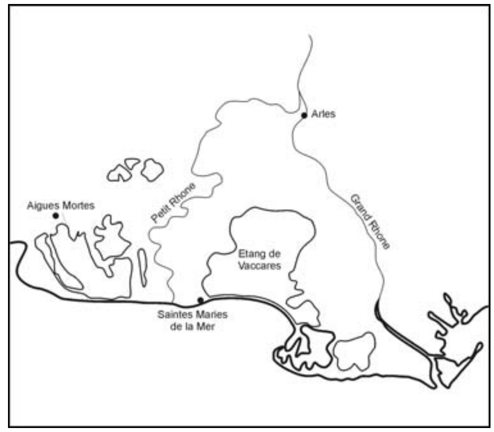


The Garonne basin with the first dams on the main rivers and the eel fishing areas. The tidal limit is at Libourne and Langon.

6.10 Camargue

The Camargue (delta of the river Rhône, Southern France) comprises 11,000 ha of streams and marshes, characterised by shallow water and low salinity levels. Yellow and silver eels are caught using fyke nets. Recruitment, fishing effort and stock abundance and structure have been recorded since 1993, enabling the calibration of complex models of main aspects of eel biology. The Camargue system thus provides a good data set to study eel dynamics in typical Mediterranean brackish lagoon fisheries.

Figure 13. The typical lagoon fyke net fishery in the Camargue. (Photos: Alain Crivelli)



7 Outline of SLIME models

Six different models have been reviewed within the SLIME project. A brief introduction to each model and a discussion of their major strengths and weaknesses is presented below. More detailed descriptions can be found on the project-CD and web-site (www.DiadFish.org/English/SLIME).

7.1 Scenario-based model for eel populations (SMEP)

SMEP models the freshwater phase of the eel population within a river catchment, considering both the biological characteristics and potential anthropogenic influences. The user may vary anthropogenic influences and levels of recruitment in order to create 'what-if' management scenarios, relative to the given reference point. Also, SMEP can be used to reconstruct the historic sizes of the eel population, either under pristine conditions and recruitment or to find the initial pre-exploitation level of equilibrium recruitment that will produce a simulated population structure in a user-specified reach and year that best matches the observed data.

The model applies recruitment and density-dependent growth, sexual differentiation, mortality and migration tendency, and maturation to undifferentiated, yellow (male and female) and silver (male and female) eels within four seasons and for each reach in the catchment. It can use default values of these biological parameters (from literature) plus length-weight relationships, reach dimensions and carrying capacity and length-weight relationships. Where site-specific data are available, they can be used to validate or alter any of the above parameters, and to define one or more reference states for the population based on densities, length-frequency distributions, sex ratios, trends in recruitment, (including stocking), fishing mortality as catch (numbers per length class or life stage) and effort, and changes to habitat/environmental quality and the impact of barriers to migration.

SMEP is designed to provide deterministic or stochastic time series or equilibrium outputs for each reach and summarised for the catchment for: undifferentiated eels, male and female yellow and silver eels: in terms of numbers, density and biomass, length-frequency distributions, sex ratios, and predicted catch numbers and biomass.

SMEP was originally developed as a generalist model for UK eel populations, and has been applied to data for the Severn and Piddle/Frome (UK) and Burrishoole (IE) within LIME.

The main strength of SMEP is that it is a general eel population model that works with limited data to simulate a variety of effects. It incorporates carrying capacity and density dependence, and is not derived from a specific data set, so it is applicable to any population, and gives outputs for all life stages, thus providing for proxy reference points. It is user-friendly, operating on any MS-DOS pc, and its stochastic modelling feature allows for sensitivity analysis.

Its main weaknesses are that it relies on assumptions about eel population dynamics for which there is limited scientific evidence. Resources required for further model development include access to GIS catchment data, estimates of carrying capacity for a variety of habitats (monitoring resources), experimental evidence to support some assumptions about eel population dynamics, and sensitivity analysis on reach definitions and parameters within the model.

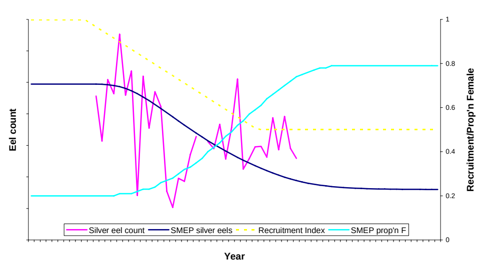


Figure 14. Observed and predicted (SMEP) decline in silver eel production from a catchment due to a 50% reduction in glass eel recruitment over 30 years. Also shown is the predicted reversal in silver eel sex ratio.

7.2 Glass eel model to assess compliance (GEMAC)

GEMAC was developed to investigate how glass eel fisheries and intake pumping affect the number of settled glass eels per area in a specified estuary. It computes the proportion of settled glass eels relatively to un-fished conditions, with or without pristine recruitment, and under different management scenarios. It is also helps to derive proxies, and can be run in data-poor situations.

Three statistical assessments describe annual, monthly and daily trends in recruitment. The input data are latitude, year, catchment area, temperature, salinity, flow and filtrations (fishery and intakes). A daily modelling simulates the effect of anthropogenic mortality, natural mortality and migration in several areas of the estuary. Daily transformed values of salinity and temperatures are used to calculate a pigmentation time, which determines the pigmentation stage structure (used as a derivative for age structure) and settlement process.

The model outputs are % settlement per glass eel recruit, number of settled glass eels with current or a pristine level of recruitment, pigmentation stage structure, catches and glass eel escapement (numbers or densities per m3).

GEMAC was originally developed with reference to the Vilaine (FR), and has been applied to the Gironde (FR).

The main strengths of GEMAC are that it was built to assess compliance and will be easily adapted to derive proximate criteria. It relates fishing effort and fishing mortality and allows testing of management scenarios. It can easily be adapted to data-poor situations (recruitment and catches unknown) and still estimate a proportion of escapement relative to unfished conditions. Where data allow, it will provide an escapement target of settled glass eel, the starting point of all other models. Even with no glass eel fisheries, the model can be used to estimate the recruitment of glass eel at the mouth of an estuary, either as a monthly recruitment index according to the latitude, or a daily recruitment if parameters such as flow and temperatures are known. The estimation of fishing and intake mortality is quite robust, and the model is not sensitive to parameter variation.

GEMACs main weakness is that it needs further validation and calibration in several estuaries. The pigment stage structure is based on one experiment using glass eels in captivity that might not replicate pigmentation in the wild. Estimates of absolute recruitment, catches and density re needed to calibrate settlement along with fishing mortality, as the two processes lead to the disappearance of glass eel from the fishing area. There is also uncertainty about the level of natural mortality.

Resources required for further development of GEMAC are data on absolute recruitment provided by IndicAng and modeling of settlement processes.

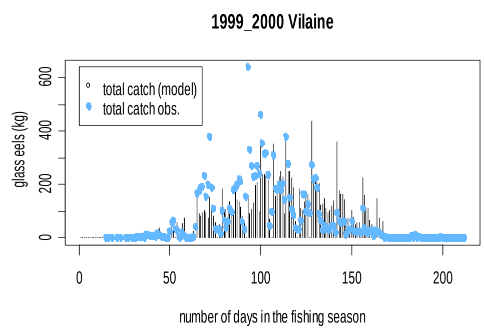


Figure 15. Observed and predicted (GEMAC) glass eel catch in the Vilaine basin for the season 1999-2000. Day 1 correspond to October 1st 1999.

7.3 Demographic Camargue Model (DemCam)

DemCam provides a realistic description of the status of the stock in a homogeneous water body considering the main aspects (both natural and anthropogenic) that affect eel population dynamics. The model evaluates the consequences of fisheries (separately for glass, yellow and silver eels), restocking, maturation, growth and natural mortality on the yellow and silver eel population. The model is designed to simulate the condition of the stock in actual, pristine and future conditions under different scenarios.

The model is deterministic and age-structured with an annual time step, using density-dependent juvenile mortality, growth of undifferentiated, male and female eels, fishing mortality and length-dependent maturation. The model requires annual indicators of recruitment and fishing effort and biological parameters either directly assessed for the studied population (when data are available) or taken from literature.

The output consists of biomass and number of eels in catches, and yellow and silver eel stock by age, length, sex and maturation structure under different management scenarios, such as stocking, fishing regulations, and/or different environmental conditions.

DemCam was originally developed for the Camargue (FR), and has been applied to Lough Neagh (UK), Lake IJsselmeer (NL) and the Shannon (IE) within SLIME.

The main strength of DemCam is that all functions have biological meaning and are calibrated. Its main weaknesses are that natural mortality is taken from the literature (not calibrated), and the sex ratio at differentiation is fixed (when data are lacking).

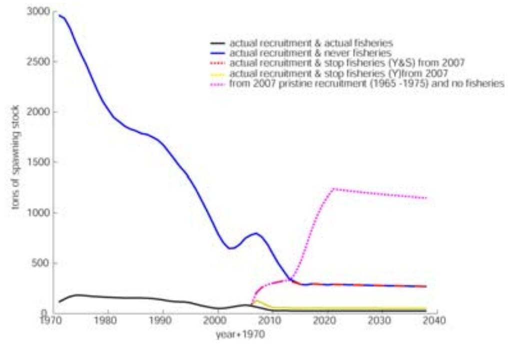


Figure 16 Predicted tons of spawning stock for the IJsselmeer case under different management and recruitment scenarios.

Resources required for further model development include sex differentiation in small yellow eels and mark-recapture estimates of yellow and silver eel abundance. There is also a need to calibrate the model against length structures of yellow and silver eel catches, to have the ability to carry out sensitivity analyses on parameters and output, and to bootstrap input data.

7.4 GlobAng, a model of eel population dynamics within a hydrographical network

GlobAng is designed to perform simulations of eel population dynamics within a hydrographical network. After calibration with real field data, the model is able to evaluate the putative pristine silver eel escapement and that in response to a variety of management scenarios, especially when the spatial (reach) dimension is important.

The model integrates growth, recruitment, sexual differentiation, maturation, natural mortality and migration within a watershed. Impacts of fishing and migration barriers can also be simulated. The time step is the week. Sex determinism, natural mortality and movement depend on density. GlobAng requires a description of the connectivity and carrying capacities of the river tree reaches and a recruitment time series. Biological features could be modified according to specific case studies. Additional data, such as time series of age structure of yellow or silver eels or eel population distribution throughout the catchment, are required for calibration and validation procedures. The main outputs are sex and age structure of yellow eels in each reach and silver eel escapements either for long run (equilibrium) or over time.

GlobAng was originally developed for the Gironde (FR), and has been applied to the Piddle (UK) and Burrishoole (IE) within SLIME.

The main strengths of GlobAng are that it takes the river tree into account, offers the possibility to test spatial management actions and, because fish movements are explicitly simulated, it can be used to analyse impacts of barriers on population dynamics. The model also integrates density dependence in processes and therefore non-linearity in the relationship between recruitment and silver eel escapement.

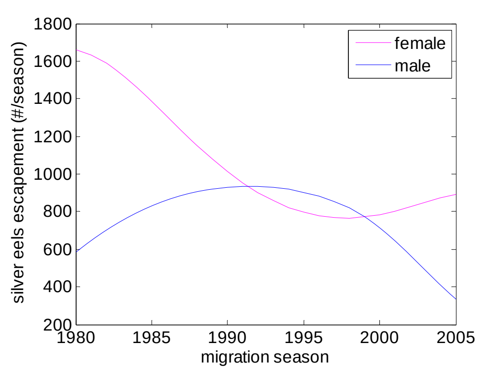


Figure 17. Predicted (GlobAng) female and male silver escapement following the decrease of recruitment observed in a catchment.

Its main weaknesses are that growth is not included, the concept of catchment carrying capacity is difficult to use, and there has been no success in calibration by optimization.

Resources required for further development of GlobAng include data for calibration, especially in large basins, and modelling using field experiments for specific processes (e.g. movement).

7.5 Swedish analytical models (SWAM)

SWAM was developed to investigate how yellow and silver eel fisheries, fishery restrictions and glass eel restocking affect the present and future spawner escapement (and catch) in a specified homogenous water body. The estimated present and potential spawner escapements can also be related to estimated escapement at some earlier time representing a more pristine stock. Following classic fishery modelling, only recruitment, mortality (natural and fishing) and average growth are considered annually. Both equilibrium and time-dependent deterministic solutions can be derived. In general, only externally determined parameter estimates are used as input, but recruitment time series can also be incorporated. No tuning or calibration process is incorporated in the models.

The main output is proportional spawner escapement, either as equilibrium solutions or over time since management actions have been applied. Depending on available input, estimates can be made of silver and yellow eel catch and spawner escapement in numbers (or biomass) or recruitment into the yellow eel fishery (in numbers) for a specific year (based on data on yellow eel catch).

SWAM was originally developed for the Swedish (coastal) fisheries (west and east coast), and has also been applied to Lough Neagh (UK), Lake IJsselmeer (NL), and the Shannon (IE) within SLIME.

The main strengths of SWAM are its simplicity, transparency and flexibility (it can be applied to many different types of systems, using little data), and that it gives analytical solutions that are well defined and do not depend on simulations (no black boxes), and allow for changes between what is used as an input or an output (e.g. either using data on either recruitment or catch).

Its main weakness is that it is dependent on parameter estimates from other sources, and that it omits many (possibly important) biological processes (e.g. using one size where all eels of one sex silver or migrate, or for sexual differentiation).

Resources required for further model development include data on the silvering process and migration.

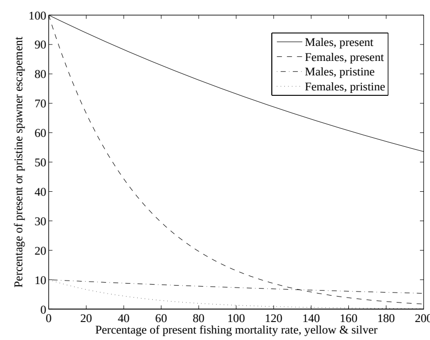


Figure 18. Predicted (SWAM) spawner escapement as a function of fishing intensity. Upper two and lower two curves: historical (pristine) or present level of recruitment.

7.6 Length-based virtual population assessment (LVPA)

The LVPA model quantifies the population state and the impact of fishing, based on total landings in numbers by length class in recent years. The model aims to provide a critical post-evaluation of management measures implemented during the data years. A minimum of assumptions and a maximum of data ensure a close tracking of the true population. Derivation of reference points is straight forward, but has not yet been elaborated. Following classic fishery modelling, only recruitment, mortality (natural and fishery induced), growth and maturation by size class to the silver eel stage and subsequent escapement each year are considered.

The model requires data on total number of eels landed per size class per year, derived from landings statistics and catch composition sampling. A breakdown of catches by gear type results in gear-specific outputs. Additionally, parameter values are required for growth, and for natural (non-fishery) mortality.

The outputs are population numbers, partial fishing mortality for each gear type, and silver eel escapement (all by year and length class).

The LVPA was originally developed for Lake IJsselmeer (NL), and has been applied to the Shannon (IE) within SLIME.

The main strengths of LVPA are its high data dependency and the low number of assumptions that allow it to represent the actual status of the stock. Where deviations occur, this usually shows up in the output, although recognizing and interpreting this might sometimes be difficult.

Its main weaknesses are the use of a closed system and mixed population, with simple growth and maturation (both could be measured), but no migration, etc., that restricts it application to lake fisheries. Also, the input must be a continuous series of annual length frequencies of commercial landings.

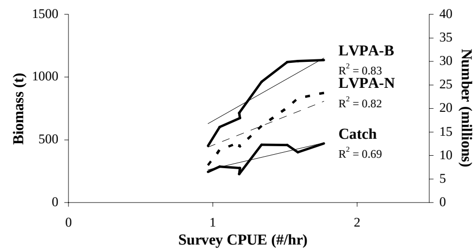


Figure 19. Correlation between commercial Catch, LVPA estimates of population Biomass/Numbers and independent trawl survey CPUE.

8 Relationships and connections between SLIME models

On the project CD and web-site (www.DiadFish.org/English/SLIME), we present a critical review of eel population dynamics models developed for eels, most of which have focused on sub-populations within specific brackish or inland water bodies. These models have been developed along three major lines: age or length group progression approaches; input-output models that directly relate juvenile abundance to migrating mature eels; and stage and/or size structured population models which may sometimes account explicitly for the observed variability of eel life history traits.

Figure 20 illustrates how the models are perceived to relate to each other, with the simulators (SMEP GlobAng, GEMAC) contrasting with the rigorous, calibrated, mathematical models (DemCam, SWAM, LPVA), and process-based models (SMEP GlobAng, GEMAC, DemCam) versus analytical model (SWAM, LPVA). The line width illustrates the perceived usefulness of combining (not merging) each model with one other.

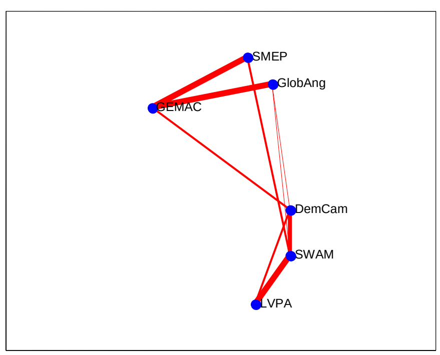


Figure 20. The similarity between the various models used in SLIME.

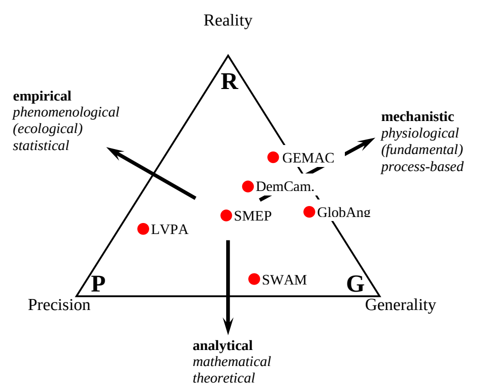


Figure 21. Positioning the SLIME models in relation to Realism, Precision and Generalism (After Levins 1966).

This suggests that there is a complementarity of stage between GEMAC (glass eel) and SMEP or GlobAng (elvers to silver eels), and of use between SWAM and DemCam (prospective scenarios) or LPVA (post evaluation).

The review on the CD and web-site discuss eel population models in terms of mathematical complexity and their usability, amount and quality of data required for calibration, realism in the description of life cycle and demographic parameters, and potential for analysing different fisheries management strategies. Given the high number of unknowns and the need to provide managers with quantitative advice in which they can have confidence (and \ be able to assess the risks involved), we emphasize the need to explicitly model uncertainty in parameter estimation and environmental and inter-individual variability, e.g. by using bootstrap techniques and Monte Carlo simulations.

While site-specific analyses are needed to provide an understanding of eel dynamics and anthropogenicic influences such as fishing, dams, habitat modification and pollution, there is a requirement to develop generalised, realistic, and precise models to evaluate eel population status and possible management scenarios in catchments throughout Europe where few data are available.

9 Using SLIME in the development of Eel Management Plans.

The European Commission has initiated the development of a Community Action Plan for Management of the European Eel (COM 2003, 573), and recently proposed a Council Regulation establishing measures for the recovery of the stock of European eel (COM 2005, 472). The corner stone of this proposed Regulation is the development of national/regional Eel Management Plans by Member States. These Eel Management Plans must include the means to manage the local eel stock against sustainability targets set at the European level, and means to monitor and verify the attainment of that objective. The SLIME-project supports this process by the development and testing of tools for stock evaluation and for deriving reference points for sustainability, and by modelling the potential effect of legal and technical measures aimed at stock recovery. Using general knowledge of eel biology and the data that were available for the case studies, our models yield an initial assessment of the status of the stock in relation to sustainability targets. Exploration of potential management measures in a model study quantifies the management options available.

Ten cases selected for their data availability have been studied within this project, which constitutes a very small subset of the eel's total distribution. Application of models to other cases will therefore often suffer from reduced data availability, both to assess the local situations and to tune the model. The available models differ in the amount of data they require, and in their applicability to specific situations. Thus, case-specific considerations will determine what model to choose, and what data to collect. A general base-line for the collection of data on eel stock and fisheries under the EU Data Collection Regulation has been developed in a Workshop in Sånga Säby (Sweden) in 2005 (Dekker 2005); implementation of the EU Water Framework Directive will yield information on available habitats, their quality and accessibility for eel. Clearly, the SLIME models do not yet have the form of a user-friendly and publicly accessible tool for everybody's use. Substantial support from experts, both on modelling and on the local eel stock, will be required. A list of partners and contributors is presented on the project CD and web-site (www.DiadFish.org/English/SLIME), to act as a kind of 'Yellow Pages' for further assistance in the development of national Eel Management Plans.

Photo: Håkan Wickström

10 Recommendations

The SLIME project was initiated to collate separate initiatives developing eel modelling tools, to apply these tools to real data and to compare and contrast approaches and results. Most of these models were initiated in recent years in response to the scientific advice to protect and restore the stock and will be available to help to develop Eel Management Plans on a catchment basis. Only two of the six models were initiated before (early 1990s), and these two have become derelict for their original application. No model is currently used in support of actual management actions. As a consequence, further development of the models will be required. This will need to focus amongst other things on:

Firstly, validation of the current models. Given the poor understanding of eel population dynamics in general, and the scarcity of data in most practical settings, the validity of current models should be carefully checked, and model deviations analysed and amended.

Secondly, improvement of our understanding of the basic biological processes governing the population dynamics of the eel, such as natural mortality, growth, migration, sex differentiation and silvering. It may also be important to understand how each of these processes is modified in response to density, in order to account for density-dependent effects in restoration actions.

Thirdly, standardisation and convergence towards a common tool box. The eel Regulation proposed by the Commission heavily relies upon national/regional Eel Management Plans; which are to be evaluated by the Scientific, Technical and Economic Committee for Fisheries. This evaluation process will be made easier with a limited number of tried and tested assessment procedures. Whilst the wide variety in catchment characteristics may lead to the development of even more diverging approaches, duplication can be avoided, and the approach and presentation can be standardised.

Fourthly, application of models in specific cases, supporting the development of river basin-specific Eel Management Plans. Where management measures are required, the current model outputs formulated in terms of process parameters will need to be translated into practical measures, quantifiable in the field. Moreover, monitoring and post-evaluation of the effect of management measures have as yet hardly been considered.

Fifthly, simplification of the current models, for application in data poor situations. The case studies within SLIME were selected for their availability of data, but in most management units there is little or no data. As a complete data collection programme will be extremely expensive, a critical evaluation of simpler approaches and minimum data requirements will be required.

Finally, the SLIME project focused on the development of models of the eels population dynamics. Obviously, this is just one aspect of sustainable eel management, and attention should also be paid to other aspects, such as the socio-economic effects of management measures, the value and impact of small scale rural fisheries, and operational aspects of national/regional Eel Management Plans.


Photo: Laurent Beaulaton

11 References

Dekker W. (ed.) 2005 Report of the Workshop on National Data Collection for the European Eel, Sånga Säby (Stockholm, Sweden), 6 – 8 September 2005.

ICES. 2005 International Council for the Exploration of the Sea. Report of the ICES/EIFAC Working Group on Eels. ICES C.M. 2005/ I:01.

ICES. 2006. Report of the joint EIFAC/ICES Working Group Eel (WGEEL), 23–27 January 2006, Rome, Italy. ICES CM 2006/ACFM:16. 350 pp.

Levins, R., 1966. The strategy of model building in population ecology. American Scientist. 54: 421–431.

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13 CD

The CD in this page provides access to technical reports, documenting all parts of the SLIME project, which can also be found on our web-site (www.DiadFish.org/English/SLIME). By offering the reader this short and readable main report, in combination with full documentation on the CD and web-site, we hope to serve the generalist and specialist alike.