

# Annex A. Detailed descriptions of the assessment models examined in this project

## A1. DemCam

### Authors

Bevacqua, D., Melia, P., Crivelli, A. J., Gatto, M. & De Leo, G. A.

### References

Bevacqua, D., Melia, P., Crivelli, A. J., Gatto, M. & De Leo, G. A. (2007). Multi-objective assessment of conservation measures for the European eel (*Anguilla anguilla*): an application to the Camargue lagoons. *ICES Journal of Marine Science* 64, 1483-1490.

### Summary

DemCam was developed specifically for the assessment of eel stock and catches in environments such as lagoons, low-lying water systems or uniform areas of rivers. A general formulation makes it suitable to describe the demography of different eel stocks, provided that sufficient data are available for the calibration of parameters. The model covers the continental phase of the life cycle, from the recruitment at the glass eel stage until the escapement of silver eels. It defines the eel stock and the harvest on an annual basis, structured by age, length, sex and stage (glass, yellow or silver eel).

### The model process

The model specifically takes into account:

- recruitment variability from year to year
- carrying capacity of the system and density dependent survival of glass eels and adults
- density dependent sex ratio
- separate growth paths for undifferentiated, male and female eels
- sex- and size-dependent natural mortality
- sex- and size-dependent sexual maturation
- fishing mortality depending on fishing effort and fish size, described in terms of gear selectivity and/or minimum landing size
- possible extra mortality on silver eels during migration

The model can be used to simulate the efficacy of different scenarios relevant to juvenile recruitment, fishing pressure and obstacles to migration.

### Detailed description of the model

The model mimics the population dynamics of different cohorts of eels, with annual time step  $t$ . The population is structured in age and maturation stage, with the state variable given by  $N(t,x,s)$  indicating the abundance at time  $t$  of eels having age  $x$  and in maturation stage  $s$  (maturation stage can be undifferentiated, yellow males, yellow females, silver males, silver females).

### Juvenile recruitment

Any considered system is characterized by a settlement carrying capacity  $S_{MAX}$ , representing the maximum number of settlers (recruits) that the system can sustain annually. This is a key parameter that determines density levels and consequent sex ratios (values of  $S_{MAX}$  usually range between 500-2000 elvers per hectare (ha) according to the system productivity).

Every year, a glass eel recruitment (or stocking) of  $R$  individuals occurs in the system. Where elvers are stocked into the system, these are assumed to have  $\frac{1}{4}$  of probability of surviving to become yellow eels, when compared against wild recruiting glass eels (Dekker, 2000).

Whatever the value of glass eel recruitment  $R(t)$ , no more than  $S_{MAX}$  elvers can enter the system and contribute to cohort strength. In fact, the survival probability of recruited glass eels to the elver stage is computed as  $1/(1+ R/S_{MAX})$  and consequently the effective number of settlers is computed as  $S(t) = R(t) * 1/(1+ R(t)/S_{MAX})$ .

### Sex ratio

The fraction of males in the recruiting cohort is set as:

- 0.25, if  $S(t)/S_{MAX} < 0.25$ ;
- 0.75, if  $S(t)/S_{MAX} > 0.75$ ;
- and  $S(t)/S_{MAX}$  otherwise.

### Growth

Growth has been estimated following the approach of Andrello *et al.* (2011) who adopted the eel growth model of Melià *et al.* (2006) to any other eel stock, providing that the age and length at silvering of males and females are known (See Andrello *et al.*, 2011 for details).

Individual weight  $w$  [g] is estimated from body length [cm] as  $w = a * l^{b}$ , where  $a = 8.34 \cdot 10^{-4}$  and  $b = 3.17$ . These are the average parameters for weight/length relationships of *A. anguilla* from studies across Europe, as reviewed by Bevacqua *et al.* (2011).

### Natural mortality

Natural mortality was estimated using the model of Bevacqua *et al.* (2011) that allows an estimate of mortality rates as a function of eel sex, size, mean annual water temperature and local densities of eel. The density level at time  $t$  is computed as a function of standing stock density  $N(t)$  and elver carrying capacity  $S_{MAX}$ . Particularly, if  $N(t)/S_{MAX} < 1$ , density is assumed to be low, if  $1 < N(t)/S_{MAX} < 2$ , density is assumed to be average, and if  $N(t)/S_{MAX} \geq 2$  density is assumed to be high (see Bevacqua *et al.* 2011 for details).

### Fishing mortality

Fishing mortality rate is estimated as  $F = q * E(t) * \phi$ , where  $q$  is catchability (a parameter representing eel susceptibility to the fishing gear),  $E$  is fishing effort (measured as number of gears per day per hectare) and  $\phi$  is gear selectivity (ranging from 0 to 1) depending on mesh size and increases with fish size (see Bevacqua *et al.*, 2009 for details). If a minimum landing size (MLS) is employed,  $\phi$  is assumed equal to 0 for fish sizes  $<$  MLS. Note that if the data provider is able to provide a reliable assessment of fishing mortality rate  $F(t)$ , data of  $E$  and  $q$  are not required.

### *Sexual maturation*

The probability that an eel will become sexual mature (silvering) at any length is computed according to the model of Bevacqua *et al.* (2006) with parameters modified according to the average maturation size and age of eel in the study system, as in Andrello *et al.* (2011).

### *Migration mortality*

The model allows for an extra mortality on silver eel due to their susceptibility to obstacles during their downstream migration. In this case, an extra survival fraction for silver eels,  $\sigma_s$ , can be considered before estimating the silver eel escapement.

## Data requirement

The model requires time dependent data which might differ between years, and constant data which mainly reflects characteristics of the system and, for sake of simplicity and absence of reliable data, are erroneously considered as constant. The data requirements under these two classes are set out below:

Time dependent data:

- habitat availability at year  $t$  (ha)
- glass eel recruitment + stocking at year  $t$  (kg)
- elver recruitment + stocking at year  $t$  (kg)
- fishing effort at year  $t$  (# gears per day)

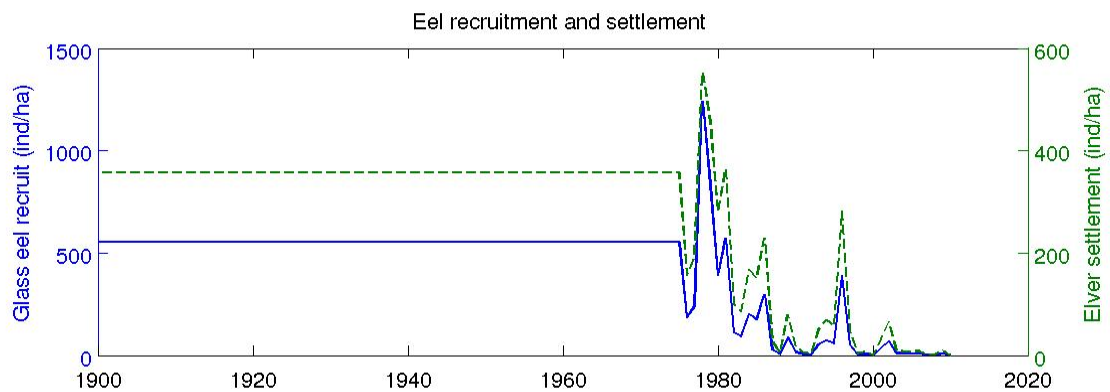
Constant data:

- first year of simulation
- last year of simulation
- system carrying capacity (elvers per year per hectare)
- survival probability from glass to elver stage (to convert elver to glass eel stocking)
- annual average water temperature
- average weight of a glass eel
- average weight of an elver
- parameters  $a$  and  $b$  used in the allometric relationship  $w=a \cdot l^b$
- stretched mesh size (mm)
- minimum landing size (mm)
- yellow eel catchability  $q_Y$
- silver eel catchability  $q_S$
- average age for male silvering (yr)
- average age for female silvering (yr)
- average length for male silvering (mm)
- average length for female silvering (mm)

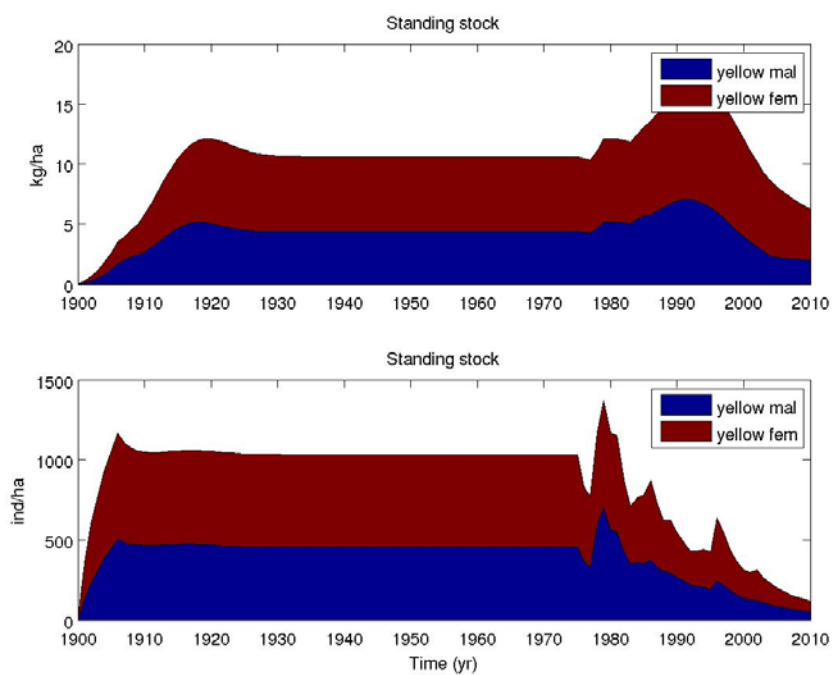
## Model Outputs

The model assesses the stock abundance and population structure in terms of age, sex and maturation stage in every year of the simulation. The state variable is initially set equal to zero, hence all age classes are fully represented in the modelled stock when  $n$  years have passed, where  $n$  corresponds to the maximum eel age observed in the system.

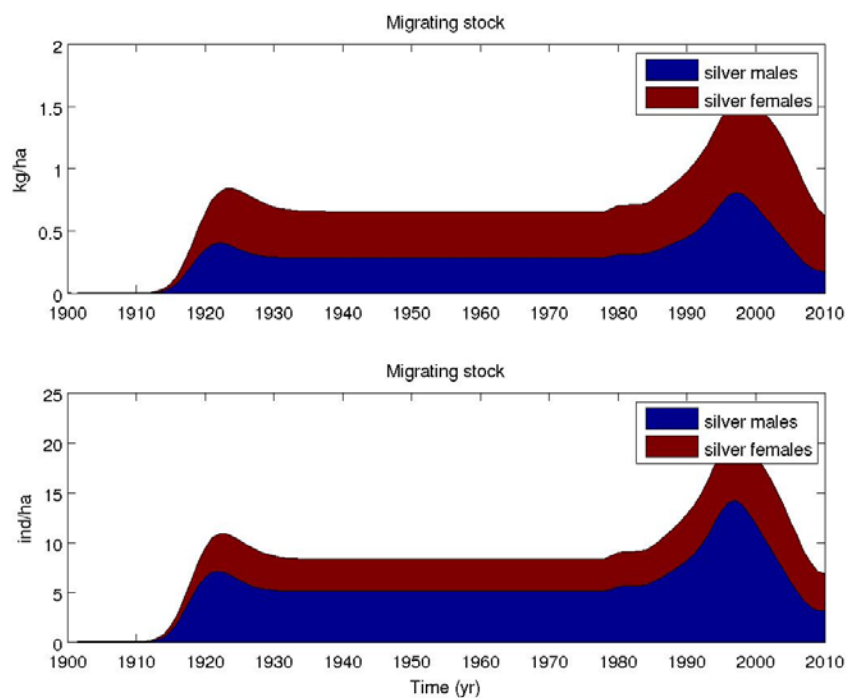
The results are saved in matrices having  $n$  rows and  $t$  columns, where  $t$  is the number of simulated years. The model produces matrices relevant to both abundance and biomass of standing stock, harvest and migrating stock (separately for males and females). The main results can be illustrated in figures. For example, Figures A1.1, A1.2 and A1.3, illustrate predicted time series of recruitment, yellow eel standing stock and silver eel production, respectively.



**Figure A1.1. DemCam simulation of glass eel recruitment and elver settlement over a 110 year time series. Note that the two y-axes show different scales, though both present individuals per hectare.**



**Figure A1.2.** DemCam simulation of standing stock of yellow eel over a 110 year time series. The top chart shows yellow eel stock for males (blue) and females (red) measured in kg per hectare, while the lower chart shows the same time series but expressed as individuals per hectare.



**Figure A1.3.** DemCam simulation of silver eel production over a 110 year time series. The top chart shows silver eel production for males (blue) and females (red) measured in kg per hectare, while the lower chart shows the same time series but expressed as individuals per hectare.

## A2. Eel Density Analysis 2.0 (EDA)

### Authors

Céline Jouanin<sup>(1)</sup>, Cédric Briand<sup>(2)</sup>, Laurent Beaulaton<sup>(3)</sup>, Patrick Lambert<sup>(1)</sup>

(1) Cemagref Bordeaux, 50 avenue de Verdun, 33612 Cestas cedex, (2) Institution d'Aménagement de la Vilaine, 8 rue Saint James, 56130 La Roche Bernard, (3) ONEMA, "Le Nadar" Hall C, 5 square Félix Nadar, 94300 Vincennes, France.

### References

French Eel Management Plans.

### Summary

EDA 2.0 (Eel Density Analysis) is a modelling tool which allows the prediction of yellow eel densities and silver eel escapement. The model is based on a geo-localized river network database, the CCM v2.1 (Catchment Characterisation and Modelling) (Vogt *et al.*, 2007). The model is applied in France at the national level, and within the POSE project has been applied to 9 eel management units located in several European countries.

The principle of the model is to extrapolate yellow eel densities from surveys to those in each reach of a river network, calculate the overall yellow eel stock abundance, convert these to silver eel equivalents and to estimate silver eel escapement by subtracting silver eel mortalities due to anthropogenic factors. It is also possible to give an estimate of the pristine escapement by running the EDA model with anthropogenic conditions artificially set to zero and time variable sets before 1980.

### Introduction

EDA is a framework of eel density analyses rather than an end-user model. The basis of this methodology is that it is more efficient to calculate silver eel escapement with an indirect method based on yellow eel density, because direct estimations of silver eel densities are rare and difficult to extrapolate at the Eel Management Unit (EMU) scale.

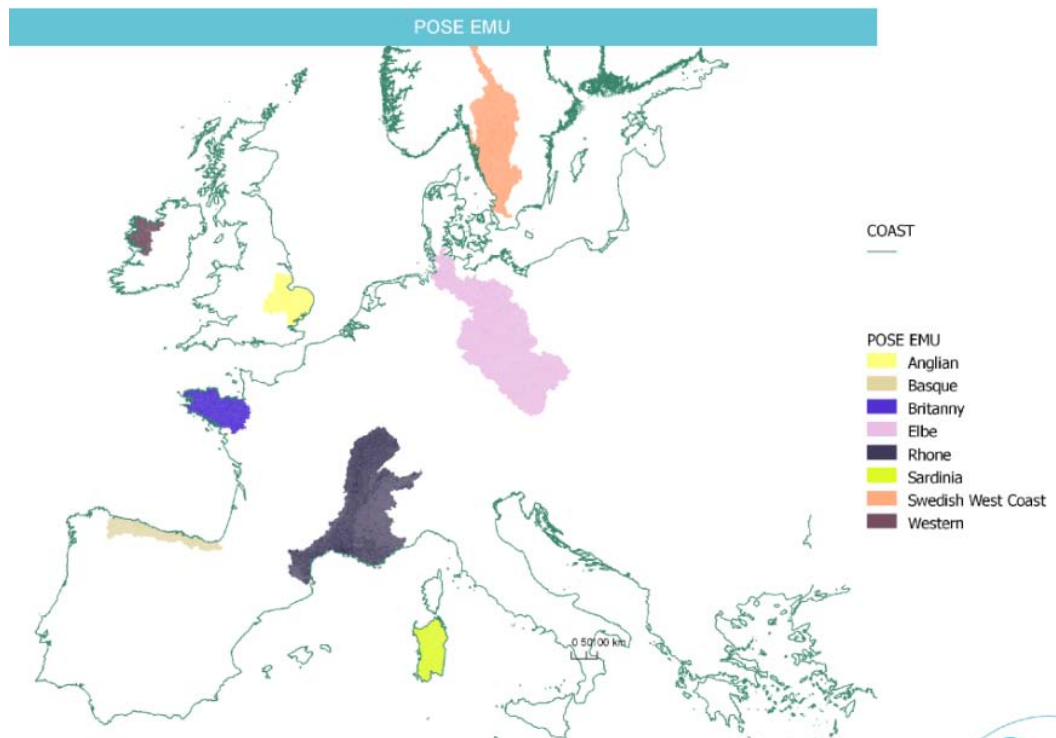
The modelling tool is based on a geo-localized river network database and designed to predict yellow eel densities and silver eel escapement. There are six main steps in the model application:

1. Relate observed yellow eel presence/absence and densities to habitat descriptors;
2. Extrapolate yellow eel densities from surveys to each river stretch by applying the statistical model calibrated in step 1;
3. Calculate the overall yellow eel stock abundance by multiplying these densities by the wetted area of each stretch;
4. Estimate a potential silver eel production from each stretch by converting yellow to silver eel abundance with a 5% rate of conversion;
5. Calculate the effective silver eel escapement by reducing production by mortalities during the downstream migration; and,
6. Sum the effective escapement from all the stretches to give an estimate at EMU scale.

## EMU descriptions

EDA is designed to be applied at the Eel Management Unit. In the POSE project it has been applied to the French “Brittany” and “Rhone”, the Irish “Western”, the Spanish “Basque”, and the English “Anglian” River Basin Districts (Figure A2.1). It has not been applied to the following places:

- German “Elbe” River Basin District where eel stock is mostly based on restocking. Though the number and places restocked were available, the large number of yellow eel electro-fishing data necessary to calibrate the model could not be gathered easily.
- Swedish “Swedish West Coast” River Basin District which corresponds to open sea and for which there are no data on eel densities.
- Italian “Sardinia” River Basin District where the only data available were for the lagoons and eel density data were not available.



**Figure A2.1. Map of Europe showing the locations and areas of the Eel Management Units which were considered for the application of EDA**

## Data Requirements

The model requires data describing the abundance of yellow eel. These data are typically represented as density ( $d$ ), calculated for electro-fishing operations corresponding to catches during at least two electro-fishing passes, divided by the wetted surface area surveyed, and expressed as number eels per 100m<sup>2</sup>.

These densities are analysed in relation to a series of habitat descriptors as potential explanatory variables. The descriptor parameters are related to the characteristics of the river basin and the anthropogenic conditions (obstacles and land use). Most of the data on habitat variables are taken from the CCM v2.1 (Catchment Characterisation and Modelling), a European hydrographical database based on a topographic model (Vogt *et al.*, 2007, <http://ccm.jrc.ec.europa.eu/>). The CCM2 database includes a hierarchical set of river stretches and catchments based on the Strahler order, a lake layer and structured hydrological feature codes based on the Pfafstetter system (De Jager *et al.*, 2010). The primary catchment unit is the drainage area – this is the smallest entity in this hierarchy and is drained by CCM river stretch. This system allows the identification of all upstream catchments and all river stretches downstream of a given point along the river network. All the river stretches are connected.

### *Stretch characteristics*

All explanatory variables are calculated at the stretch level. The following variables are calculated from the river topology of the CCM:

- Distance from the sea (km), calculated as the distance from the river mouth to the downstream node of the river stretch, plus half of the length of the river stretch;
- Distance from the source (km), calculated as the distance from upper node of the river stretch to the upstream source of that river line, plus half of the length of the river stretch;
- Relative distance (km), calculated as the distance from the sea / total distance (distance to sea + distance to source), after Imbert *et al.* (2010);
- Strahler and Shreve stream orders;
- Mean elevation (m), the average elevation in the primary catchment;
- Mean slope (°), the average slope in the primary catchment;
- Altitudinal gradient (%), the gradient calculated as [(elevation at the upstream node - elevation at the downstream node) / stretch length]\*100];
- Area of drainage directly into the stretch (km<sup>2</sup>), excluding the drainage into the upper node;
- Area of drainage upstream of the river stretch (km<sup>2</sup>).

Temperature (°C) and rainfall (ml) statistics are extracted from the CRU (Mitchell *et al.*, 2004), corresponding to the mean long-term average annual temperature and precipitations in the primary catchment.

### *River width*

The CCM2 provides data on the length of each stretch, but not the wetted area, which is necessary in order to transform eel densities to estimates of standing stock. Typically, river width is linked to the river discharge with a square-root link (Leopold & Maddock, 1953; Andrews, 1984; Julien & Wargadalam, 1995; Jiongxin, 2004; Lee & Julien, 2006; Caissie, 2006). The river discharge is approximately proportional to the drainage area, though this allometric relationship shows some regional variations (Benyahya *et al.*, 2009). Thornton *et al.* (2007) have found a direct square-root relation between the river width and the upstream drainage surface area (river width = 4.98 catchment area<sup>0.47</sup>).

However, the river width relationship tends to violate the linearity and homoscedasticity assumptions of simple linear regression. These characteristics suggest using a two-parameter power function with a multiplicative error term:  $W_i = a CA_i^b e^{\epsilon_i} \Leftrightarrow \log(w_i) = \log(a) + b \log(CA_i) + \epsilon_i$



where  $W$  is the river width and  $CA$  is the cumulative streaming area,  $a$  and  $b$  are constants and  $\epsilon_i$  is the multiplicative error term for the  $i$ th river stretch.

### *Anthropogenic conditions*

#### *Obstacle pressure*

The obstacle pressure is characterised by the cumulative number of structures (dams and weirs) from the sea to the stretch, and the accumulation of scores for the passability of eel at each structure. These scores are based on the assessment criterion of the upstream passability from Steinbach (2009, modified from Steinbach, 2006), that weights different variables of dam construction (waterfall height, roughness, structure profile) using a scoring key that penalizes (+) or facilitates (-) an eel's upstream passage.

#### *Land use*

Land use influences morphology, sediment transport and riparian vegetation, and therefore indirectly, fish populations. Catchment vegetation, especially riparian (streamside) vegetation, has been implicated as a major factor controlling fish populations in streams through its influence on availability of light, water temperature, and channel stability (Hicks *et al.*, 1991). Hanchet (1990) recognised that in-stream habitat varied between land-use types and considered this the most likely explanation for the distribution of some fish species. Hicks & McCaughan (1997) observed a strong land-use effect on fish, such that pasture streams had the highest fish density, and biomass and eel production.

Productive land uses (e.g. agriculture and forestry) have been shown to affect many of the characteristics of streams including fish (Hanchet, 1990; Jowett *et al.*, 1996). Anthropogenic landscape disturbances such as row crop agriculture, deforestation and grazing shift the structural and functional relationships among the landscape elements and the stability of the physical environment. Consequently, land-use activities result in significant alterations in the population and community dynamics of stream fishes (Schlosser, 1991).

For POSE, we used the pan-European land cover and land-use classification CORINE (Co-Ordination of Information on the Environment, CLC2006, 250m, version 12/2009) to provide land cover information in the analyses (European Commission, 1994). The data are obtained from the European Environment Agency website and are available at <http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-clc2000-seamless-vector-database-1>.

For POSE, we grouped the 44 CORINE Land Cover classes into a simplified version with 3 groups (Table A2.1), to distinguish between low (no impact), medium (agricultural) and high (urban) impacts.

**Table A2.1 Corine Land Cover grouped nomenclature.**

3 groups	Levels in CLC
Urban	1.1 Urban fabric
	1.2 Industrial, commercial and transport units
	1.3 Mine, dump and construction sites
	1.4 Artificial non-agricultural vegetated areas
Agricultural	2.1 Arable land
	2.2 Permanent crops
	2.4 Heterogeneous agricultural areas
No impact	2.3 Pastures
	3.1 Forests
	3.2 Shrub and/or herbaceous
	3.3 Open spaces with little or no vegetation
	4.1 Inland wetlands
	4.2 Coastal wetlands
	5.1 Inland waters
	5.2 Marine waters

The percentage of each land use category is calculated for each river stretch drainage area, as well as for the area of catchment upstream of each stretch.

### Detecting co-linearity

Given the range of habitat descriptors and the possibility of complex links between, for example altitude and mean annual temperature, gradient and land-use, we first explore the datasets to test for any co-linear relationships between explanatory variables. High co-linearity can result in coefficient estimates that are difficult to interpret as independent effects and/or have high standard errors (Neter *et al.*, 1990, Graham, 2003). We have decided to avoid using correlated variables in the model and therefore we tested each variable separately, as we didn't know which variable was relevant, or might have the higher ecological meaning.

We use the Spearman rank correlations coefficient rather than the Pearson correlation coefficient because the former makes no assumptions about the linearity in the relationship between the two variables (Zar, 1996). We also use the 'varclus' function in the library 'Hmisc' (Venables & Ripley, 2003; Harrell, 2002; Sarle, 1990). This function carries out a hierarchical cluster analysis, using the square of Spearman's rank correlation ( $\rho^2$ ) as a similarity metric to obtain a more robust insight into the correlation structure of (possibly non linear) predictors. We use the rule of thumb from Booth *et al.* (1994) that suggests that a correlation between pairs of variables with magnitudes greater than  $\pm 0.5$  indicate high co-linearity.

To reduce the co-linearity, a set of candidate predictors are selected in the model in such a way that co-linearity problems are minimized (Draper & Smith, 1981; Alzola & Harrell 2002). To avoid spurious correlations, a separate entry is used for the set or pairs of variables tightly correlated. For the Corine Land Cover groups, we selected only a combination of two variables because the sum of 'p\_agricultural+p\_urban+p\_other' and the sum of 'p\_up\_agricultural+p\_up\_urban+p\_up\_other' are equal to 1.

## Model selection

We calibrated statistical models with a Generalized Additive Model (Hastie & Tibshirani, 1990) to assess how the densities of yellow eel varied between years and according to characteristics of river network, land use and obstacles pressures. GAMs have been successfully applied to analyze patterns in abundance of pelagic fishes (Peltonen *et al.*, 2007), estimate population size of seabirds (Clarke *et al.*, 2003), and standardize CPUE data (Maunder & Punt, 2004).

Generalized additive models can be considered as an extension of generalized linear models involving a sum of smooth functions of covariates (Wood, 2006), replacing linear predictors by non linear predictors Eq. (1) where  $f_j$  is a smooth function (a spline smoother in our case).

$$(1) \quad g(\mu_i) = \mu + \sum_{j=1}^p f_j(X_i)$$

The main advantage of GAMs over traditional regression methods is their capability to model non-linearities using non-parametric smoothers (Hastie & Tibshirani, 1990; Wood, 2006).

GAMs models are useful to understand the relationships between environmental variables and the abundance of eel. In this statistical analysis, non-linear relationships between the response variable (yellow eel abundance) and explanatory variable were identified. The GAM approach can handle non-linear relationships with the use of smooth additive functions.

All computations were carried out with the R2.12.1 statistical software (R Development Core Team, 2011, [www.cran.r-project.org](http://www.cran.r-project.org)). The EDA model is based on a delta-gamma model (Stefánsson, 1996) which combines two generalized additive model (GAM). There are three steps to the modelling:

1. a presence/absence model (delta model) based on a GAM with a binomial distribution and a logit link to determine the probability of a positive catch;
2. a density model with the positive data (gamma model) using a GAM with a gamma distribution and logarithm link to determine the level of positive catch; and,
3. the multiplication of the two previous models (delta-gamma model).

The GAMs were computed with the library 'gam' (Hastie, 2010) with a cubic spline smoother (3 degrees of freedom) for each environmental variable. These delta-gamma ( $\Delta\Gamma$ ) GAMs explain a large portion of the variability in eel abundance data, as there are many occasions where densities are null.

The best density model is selected by the Akaike's Information Criterion (AIC), with a lower AIC indicating a better fit (Akaike, 1974; Sakamoto *et al.*, 1986). The AIC takes into account both the statistical goodness of fit and the number of parameters needed to be estimated in the model. The AIC was estimated as:

$$AIC = -2L + 2n$$

where  $L$  is the maximized log likelihood and  $n$  is the number of parameters in the model.

Similarly, the best presence-absence model is selected using Kappa coefficient (Cohen, 1960; Manel *et al.*, 2001). Kappa measures the proportion of observations correctly classified as present or absent

while also accounting for chance (Manel *et al.*, 2001). Model fits with Kappa values lower than 0.2 are considered as 'fair', with values of 0.4-0.6 as 'moderate', 0.6-0.8 as 'good' and 0.8-1 as 'very good' (Manel *et al.*, 2001; Landis *et al.*, 1977). The probability threshold used to predict occurrence tends to be correlated with Kappa (Fielding & Bell, 1997; Manel *et al.*, 2001).

Calibration plots provide a goodness-of-fit plot for presence-absence models, as described by Pearce and Ferrier (2000), Vaughan and Ormerod (2005), and Reineking and Schröder (2006). In a calibration plot the predicted values are divided into bins, and the observed proportion of each bin is plotted against the predicted value of the bin.

The Receiver Operating Characteristic (ROC)-plots (Fieldings & Bell, 1997; Guisan & Zimmermann, 2000) and the Area Under the receiver operating characteristic Curve (AUC) were estimated. The ROC methodology was used to evaluate the ability of the model to discriminate between those sites where a species is present and those where it is absent (Hanley & McNeil, 1982).

The ROC plot shows the False Positive rate (1-specificity) (X axis), i.e. the probability of incorrectly diagnosing a positive case when it is actually negative, against the True Positive rate (sensitivity) (Y axis), i.e. the probability of correctly diagnosing a positive case, across all decision levels for the diagnostic tests. In the ROC plot, the diagonal grey line is a guide for a test that has no ability of correctly identifying cases better than by chance alone. This marks a good cut-off point under the assumption that false negatives and false positives have similar costs. A test with no predictive ability produces a curve that follows the diagonal of the grid (De Long *et al.*, 1988). The ROC plot from a good model will rise steeply to the upper left corner then level off quickly, resulting in an AUC near 1.0. A poor model (i.e. a model that is no better than random assignment) will have a ROC plot lying along the diagonal, with an AUC near 0.5. The higher the curve from the diagonal, the better the fit.

To obtain the AUC, one plots the false positive fraction (1-specificity) against the true positive fraction (sensitivity) for all probability thresholds and then calculates the AUC (Fielding & Bell, 1997). The AUC is equivalent to the chance that a randomly chosen plot with an observed value of present will have a predicted probability higher than that of a randomly chosen plot with an observed value of absent. The "Presence Absence" package (Freeman, 2007) used to create the model quality graphs for binary response models uses the method from De Long *et al.* (1988) to calculate AUC.

The values of AUC ranges from 0 to 1, where a score of 1 indicates perfect discrimination, AUC values > 0.9 indicate high accuracy, AUC values of 0.7–0.9 indicate useful applications, an AUC value of 0.5 indicates that the model performs at random, and values <0.5 indicate performance worse than random (Manel *et al.*, 2001; Boyce *et al.*, 2002; Elith *et al.*, 2006). Estimations were made with the presence/absence library of the R statistical software.

In the Error Rate versus Threshold plot sensitivity, specificity and Kappa are plotted against all possible values of the threshold (Fielding & Bell, 1997).

## Silver eel escapement estimation

### *Current escapement $B_{current}$*

$B_{current}$  is the silver eel escapement of a given year.

EDA estimates the density of yellow eel at any site as:

$$\Delta\Gamma(t, m, x_{i,k}, h_{i,k})$$

the delta-gamma model that calculates the density of yellow eel in the year  $t$ , the month  $m$  according to stretch characteristics  $x_{i,k}$  (distance to sea, distance to source, mean temperature, elevation, etc) and anthropogenic pressures  $h_{i,k}$  (land use and obstacle) of stretch  $k$ .

The density of yellow eel is multiplied by the wetted surface  $S_k$  of stretch  $k$  (which is simply the product of the length of the stretch and the river width) to have the number of yellow eel in stretch  $k$ .

The total amount of yellow eel in an EMU is then estimated as:

$$\sum_k \Delta\Gamma(t, m, x_{i,k}, h_{i,k}) S_k$$

Then the potential escapement of silver eel is calculated by multiplying the yellow eel abundance in each stretch by a yellow-to-silver eel conversion rate  $\rho$ . There is little information available about the relationship between yellow eel and silver eel stocks (Acou, 1999; Robinet *et al.*, 2007; Feunteun *et al.*, 2000). Feunteun *et al.* (2000) have estimated that between 5 and 12% of the yellow eels start silvering in the Frémur catchment in any one year. In the present version of EDA, a constant conversion rate  $\rho = 5\%$  was chosen as a default value, based on the assumption of density-independent biological processes.

This potential escapement in numbers is then converted into biomass according to the mean weight of a silver eel  $w_{silver}$ , specific to each EMU.

Lastly, the current biomass  $B_{current}$  is calculated by subtracting the anthropogenic mortalities (fisheries, turbines, etc) on silver eel  $Y_{silver}$  to the potential escapement in biomass:

$$B_{current}(t, m, x_{i,k}, h_{i,k}, Y_{silver}(t)) = \rho \bar{w}_{silver} \sum_k (\Delta\Gamma(t, m, x_{i,k}, h_{i,k}) S_k) - Y_{silver}(t)$$

### Best achievable $B_{best}$

The Best achievable escapement ( $B_{best}$ ) can be calculated by the current biomass artificially forced to null anthropogenic impact (no dams, land use mortality to “no impact” and silver eel catch to 0), and adding back the silver eel biomass corresponding to anthropogenic mortalities at glass eel and yellow eel stages (ICES, 2010).

The anthropogenic mortality in biomass at glass eel stage  $Y_{glass}(t)$  is estimated as follows. The mortality in number is:

$$Y_{glass}(t) \frac{1}{\bar{w}_{glass}}$$

where  $\bar{w}_{glass}$  is the mean weight of a glass eel.

The number of silver eel that should have survived from these glass eels is:

$$Y_{glass}(t) \frac{1}{\bar{w}_{glass}} e^{-M\tau}$$

where  $M$  is the mean natural mortality coefficient over the lifespan in the EMU  $\tau$ .

High eel mortality is rather low in natural populations, about 5-10% year<sup>-1</sup> (e.g. Adam, 1997). The natural mortality ( $M$ ) is considered as constant at the annual scale and equivalent to 0.1386 year<sup>-1</sup> (Dekker, 2000).

In biomass,

$$Y_{glass}(t) \frac{\bar{w}_{silver}}{\bar{w}_{glass}} e^{-M\tau}$$

Similarly, the yellow eel mortality converted to silver eel biomass is:

$$Y_{yellow}(t) \frac{\bar{w}_{yellow}}{\bar{w}_{glass}} e^{-M(\tau - \lambda_{yellow})}$$

where  $\lambda_{yellow}$  is the mean age of yellow eel removed by anthropogenic mortalities.

Therefore, the formula  $B_{best}$  is as follows:

$$\begin{aligned}
 B_{best}(t) = & B_{current} \left( t, h_{j,k} = \emptyset, Y_{silver}(t) = 0 \right) \\
 & + Y_{glass} (t - \tau) \frac{\bar{w}_{silver}}{\bar{w}_{glass}} e^{-M\tau} \\
 & + Y_{yellow} (t - \tau + \lambda_{yellow}) \frac{\bar{w}_{silver}}{\bar{w}_{yellow}} e^{-M(\tau - \lambda_{yellow})}
 \end{aligned}$$

### **Pristine escapement $B_0$**

The pristine biomass  $B_0$  is the spawner escapement biomass produced when there were no anthropogenic impacts and recruitment was at its high historical level.

In EDA,  $B_0$  is simply the average of  $B_{best}$  for the period before 1980 (before the crash):

$$B_0 = \overline{B_{best}(t < 1980)}$$

### **Summary of the results**

We tested a large number of explanatory variables in the models (more than 12 for each of the real data sets, and 5 for the Crepe data set) (Table A2.2). The number of models tested differed between each river basin district because of either the lack of some data or differences or different variables being removed after co-linearity analysis (Table A2.3). The variables selected also differed between the presence-absence model and the density model (Table A2.3).

**Table A2.2 Number of models tested in each river basin districts.**

	Brittany	Rhone	Western	Basque	Anglian	Crepe
Nb of variables tested	17	17	14	16	16	5
Nb of model tested	3267	2160	480	765	1890	18

**Table A2.3 Variables tested and selected in the best density model for each EMU in the presence-absence model ( $\Delta$ ) and in the density model ( $\Gamma$ ).**

Variable	Brittany		Rhone		Western		Basque		Anglian		Crepe	
	$\Delta$	$\Gamma$	$\Delta$	$\Gamma$	$\Delta$	$\Gamma$	$\Delta$	$\Gamma$	$\Delta_1$	$\Gamma$	$\Delta$	$\Gamma$
year	S	S	S	S	S	S	S	S		S	S	S
month	T	T	S	T	T	S	S	S		S	na	na
elevation_mean	T	T	S	S	T	T	S	S		S	na	na
slope mean	T	S	T	T	S	S	T	T		T	na	na
altitudinal gradient	T	S	T	T	S	T	T	T		T	na	na
distance_sea	S	T	S	S	T	S	S	S		S	S	S
distance_source	S	T	T	S	T	S	T	T		S	S	T
relative_distance	T	S	T	T	S	T	T	T		T	na	na
temperature_mean	S	T	T	T	T	T	T	T		T	na	na
rain_mean	S	T	T	T	T	S	T	T		S	na	na
cs_nbdams	T	S	S	T	T	T	S	T		na	T	T
cs_score	na	na	na	na	na	na	T	S		na	na	na
up_area	T	T	T	T	na	na	T	T		T	S	S
p_urban	T	T	T	S	na	na	T	T		T	na	na
p_up_urban	S	S	S	T	na	na	S	T		S	na	na
p_agricultural	T	T	T	S	T	T	na	na		T	na	na
p_up_agricultural	T	S	T	T	T	S	na	na		T	na	na
p_no_impact	T	T	T	T	T	T	T	T		T	na	na
p_up_no_impact	S	T	S	T	T	T	T	S		S	na	na
Model accuracy:												
Kappa (for $\Delta$ model)	0.56		0.64		0.4		0.67				0.42	
% of deviance	33	54	52	48	14	37	48	51		36	31	41

**Key: S = variable selected in the best delta-gamma model; T = variable tested in the model; na = data not available; 1 = no data with null densities were available for the Anglian EMU so only the gamma model could be applied.**

As a general rule, eel densities are higher in the downstream river stretches and lower in the upstream river stretches, consistent with eel density decreasing progressively according to the distance from the sea (Smogor *et al.*, 1995, Knights, 2001; Ibbotson *et al.*, 2002; Aprahamian *et al.*, 2007) and the relative distance (Imbert *et al.*, 2008).

Yellow eel densities estimated for Brittany and Rhone (complete dataset from 1984 to 2008) showed decreasing temporal trends, whereas those estimated for the Basque EMU (from 1981 to 2009) showed increasing temporal trends. The year to year variation in eel density provides a measure of the true change in abundance, but is also highly dependent on the catch method and whether the eel is specifically targeted or not during the electro-fishing operations. When variations in estimates of relative abundance are inconsistent with the general declining trend observed in eel density throughout Europe, variations in survey catchability may be responsible. The change observed in the



Basque country is clearly due to the change in the fishing method. In earlier years, the eel was not targeted during the salmon surveys.

In addition to this general trend of reducing eel density with increasing distance from the sea, eel densities are related to the number of dams downstream of any survey site (Machut *et al.*, 2007), and hydrographic factors such as water flow rates and the depth of the river also explain part of the variation in eel densities (Goodwin & Angermeier 2003; Wiley *et al.*, 2004).

The distribution of the sampling stations was not homogeneous in any of the real data sets. Most electro-fishing is conducted on foot and therefore in water less than 1 m deep – electro-fishing from boats to sample deeper waters is possible but it is even more difficult to catch eels with this method. As a consequence of this sampling limit, there are few data for eel in the deeper waters of the downstream river stretches. This could introduce some bias in the data as densities are still extrapolated from the model in the downstream deeper waters, which correspond also to the largest densities of eel in the model. In the Basque EMU for instance, we observed peak densities in several downstream river stretches.

Most methods to analyse time series data require equidistant observations. However, the number of electrofishing operations varied considerably between years and between months in years. For example, in the Basque river district, there were up to 79 operations in some years but only two or three operations in other years. The same is true for between months, as there were more than 400 observations for the most fished month, but only 29 observations across the whole time series for the least sampled month. In some other river basin districts, no data at all were available for several years. For the Basque RBD, we used all the data that were available, but accepted that excluding factors (e.g. year, month) because of this might have affected the estimations.

The estimation for Crepe (complete dataset from 51 to 149) showed a decreasing trend during the first 70 years followed by an increase during 30 years. EDA detected a change in the trend of silver eel escapement at the year 120 using of a cubic spline smoother, but the stable period in-between the decline and increase in recruitment was not detected. The degree of smoothness of model terms could have been increased (with a degree of smoother  $s = 4, 5$  or larger). However, it was found that combined delta-gamma generalized additive models are useful in the analysis and explain a considerable portion of the variability in this type of data set, but a fairly large number of degrees of freedom is required to describe the proper behaviour of the data. An alternative is to use the year as a factor in the model.

The model has used electro-fishing data with abundances predicted by the Carle and Strubb depletion method. This means that for this implementation of the model, we restricted ourselves to the shallow sections of the river. Other data, with electro-fishing from boats, or fyke net surveys are available and could be incorporated in the model, providing we had a measure of the relative 'capture efficiency' of the different methods, which would provide an equivalent value between electro-fishing depletion estimates and catch per unit effort data from fyke nets and other traps. These data could help to provide a more realistic data set for a larger spatial scale, to include places where most sampling is achieved using with fyke netting or other gear survey (e.g. lake dominated Western District in Ireland). It would also be necessary to join all the lake surfaces to the CCM. The resources to achieve this were not available within the POSE project but data are now ready for this kind of analysis.

The EDA models considered here can be extended considerably in different ways in the future. The EDA framework allows the combination of different sets of candidate variables in the model in accordance with the database available for each EMU. We have chosen in the POSE project to test similar variables across the datasets to provide a common comparison. However, these variables might not be the best candidates according to local expertise, and in future other variables could be explored, such as catchment geology, the hydro-geological area and characteristics of river flow.

The temperature and rainfall regimes were treated as constant variables in the analysis, but the chronological series of these variables could have been used to evaluate their relationships with the yellow eel abundance. The correlation of these two variables with a lag difference in the abundance series (the rainfalls at a given month  $m$  could affect the abundance at the month  $m+1$ ) should also be tested.

There were issues with the simplified land cover groups used in the analysis. In the Basque EMU, the agricultural land use group ( $p_{\text{agricultural}}$ ,  $p_{\text{up\_agricultural}}$ ) was very close to zero, while in the Western EMU the urban land use group ( $p_{\text{urban}}$ ,  $p_{\text{up\_urban}}$ ) was not represented. To reduce this problem, different Corine Land Cover subsets could be determined for each EMU. We chose not to do so within the POSE project to provide a consistent comparison between the different EMU.

The final models were selected using Akaike's Information Criterion and use a large number of explanatory variables. However, too large number of variables could lead to an over-parameterized model (Shono, 2005) so caution should be applied in interpreting the significance of some effects in the analysis. As an enhancement to the modelling approach, it might be useful to repeat the analysis using the Bayesian Information Criterion (BIC) or consistent AIC (CAIC).

Finally, the degrees of polynomials could be increased and more interaction terms included. One crucially lacking form of data was the fishing pressure described at the stretch level. An initial testing of this kind of variable (Hoffman, 2008) showed that it was not precise enough to provide a consistent response for the model, especially for data spanning over a long time period. However, with good data, one might expect the analysis to reveal if the eel population is affected by the fishing pressure or other anthropogenic impacts.

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## A3. German Eel Model (GEM)

### Authors

Oeberst, R.

### References

Appendix of the German Eel Management Plan

### Summary

This is an age-based model developed to describe the dynamics of the River Elbe eel population with data from 1985 to 2008, and especially to estimate silver eel escapement between 2005 and 2007. The river was treated as a single unit, i.e. not accounting for spatial aspects like habitat quality, and a 94% female sex ratio was assumed throughout. GEM is based on the VPA concept, but projecting forwards. The starting population was the estimated number of eels per cohort in 1985. The population in 1986 was then estimated, accounting for natural and anthropogenic losses per cohort, and inputs of recruitment and stocking. Input data are provided as numbers per cohort, with various counts or length distributions converted to age profiles based on survey data. A weight-length relationship and growth rate are used to estimate the mean weight per cohort and to transform length-based estimates into age-based estimates. Model outputs are population size, catch by fishermen, catch by anglers, catch by cormorants, mortality by other natural reasons, and silver eel escapement, all expressed as numbers per cohort.

### Model approach and processes

The German eel model was developed specifically for describing the dynamics of the eel population of the River Elbe system (Figure A3.1), especially for estimating the escapement of silver eel between 2005 and 2007. The age-based model is data driven and was adapted to the available data series-estimated relationships. The model treats the productive area as a single unit, so does not take into account spatial aspects like different habitat patterns or area dependent growth. Nor does it account for the potential effects of density on eel production processes such as growth, sex differentiation and mortality rates.



**Figure A3.1. River Elbe system within Germany**

The model is based on the structure of the Virtual Population Analysis (VPA), but the GEM works in the opposite direction. The initial population in number, by age group, at the beginning of year 1 is estimated. Then the model estimates the number of eels of each age group which leave the system for various reasons (natural mortality, fisheries, predation, turbines) in the same year. The population at the beginning of the following year is then estimated based on the remaining population, and the numbers of immigrating elvers and restocked eels.

The following parameters are assumed to be stable during the total model period:

- Growth and weight-length relationship;
- Relative age distribution of eel eaten by cormorants;
- Relative age distribution of silvering eel;
- Mean weight of eel in the stomach of cormorants;
- Relative age distribution of immigrating eels.

The natural mortality is split up into two components: the effect of cormorants and the remaining natural mortality. It is assumed that the age distributions of eel caught in fisheries and those eaten by predators are similar to the age distribution of the stock. Also, that turbines and pumping stations only impact silver eels.

Note that, for the Elbe data set at least, analyses have shown that the size and the relative age distribution of eel in the first year of any simulation have relative little effect concerning the year  $t_x$  providing that the period between the first year and the year  $t_x$  is more than 18 years. Thus, GEM requires a 'training' data set of at least 18 years.

The model also contains the option to add stochastic 'noise' to the input data, where this is normally distributed with a mean of zero and a given variance. If the variance is realistic, this option can be used for estimating the confidence intervals of the escaping silver eels using bootstrap methods.

## Data requirements and calculations

The following input data are required for the model:

- Catch in kg by fishermen and angler per year
- Number of restocked eel by age group and year
- Number of immigrating elvers by age group and year (if data are not available for each year, estimates based on international time series can be used)
- Catch in kg by cormorants per year
- Mortality of silver eels due to hydropower plants and water removals in % per year

Input data are provided as numbers per cohort, with various counts or length distributions converted to age profiles based on survey data. The model requires descriptions concerning the weight-length relationship and the growth rates in order to estimate the mean weight of eel by age group and to transform length-based estimates into age-based estimates. For the original Elbe dataset, the total number of immigrating elvers of each year was split into numbers per age group, based on the relative age distribution of the elvers estimated by field samples between 1993 and 1997. The number of stocked eel was summarized from stocking statistics of fisherman and anglers in numbers per length group.

The relative age distribution of eel captured by cormorants is required for estimating the total number of eel consumed by cormorants. It is assumed that the proportion of eel in the diet of cormorants is dependent on the density of eel. For the Elbe simulation, samples of cormorant stomachs were used to estimate the relative length distribution (lognormal distribution) of eel eaten by cormorants. This distribution was converted into an age distribution using the eel growth function.

Relative length distributions of silver eel are used to estimate the proportion of silver eel by length. The relative length distribution can be described by two processes:

1. Assuming an increasing proportion of silvering eels with increasing length, described by a logistic function:

$$A_l = \frac{a_1}{\{1 + \exp[-1 * (a_2 + a_3 \text{Length})]\}}$$

2. Assuming a decreasing density of silver eel with increasing length due to natural mortality and migration, described by an exponential function:

$$B_l = b_1 * \exp[b_2 * (\text{Length} - b_3)]$$

The parameters of the models  $a_1$  to  $a_3$  and  $b_1$  to  $b_3$  are estimated in such a way that the sum of squared differences between the observations and the model estimates is minimized. Again, the growth function is used to transfer the relative length distribution into a relative age distribution.

The mean survival rates of silver eel due to hydropower plants and water abstractions are estimated for each year of the simulation.

Cormorant predation on eel is thought to be a significant impact on eel production in the Elbe system - there was a very strong increase of the cormorant population between 1990 and 2007. Therefore, the natural mortality is split up into two components: the effect of cormorants and the remaining natural mortality. This 'predator' component of the natural mortality model can be reduced or removed for simulations of rivers where cormorant (or other predator) impacts are thought to be less important.

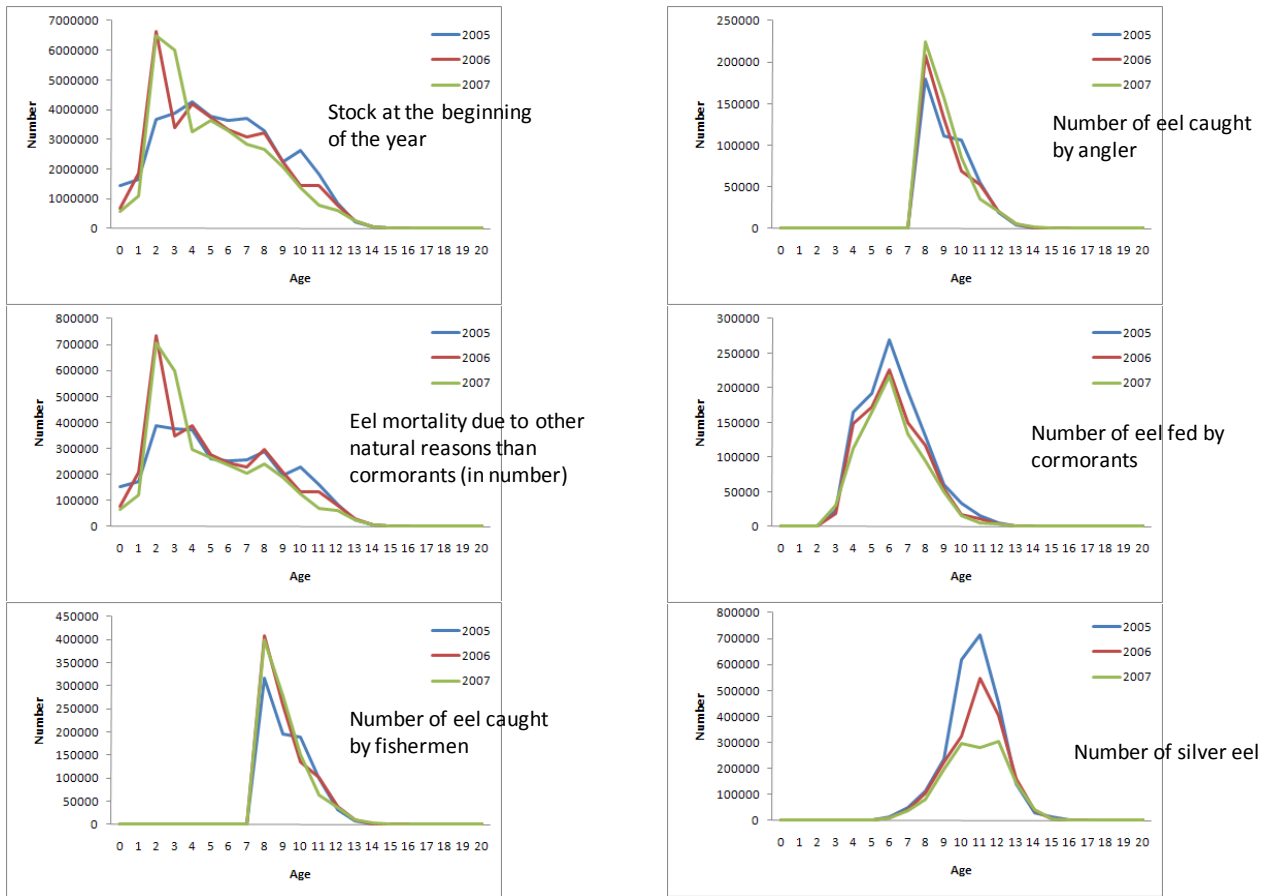
Total natural mortality was set as 13% in any year, after Dekker (2000) proposed the rate of  $M = 0.14$ . For the GEM application to the Elbe, the contribution of cormorants to the natural mortality was estimated for the year 1989 when the cormorant population was low. The maximum effect was estimated for the eel age groups 5 to 7 based on the relative length frequency of eel observed in the stomachs of cormorants. It was estimated that 2% of total natural mortality of eel was caused by cormorants, but separate rates were estimated for every length group, and ranged from 0% to 2%. In addition, a density dependent effect was taken into account based on the estimates of Lough Neagh (ICES 2007).

Finally, the following field data are required for optimizing the model parameters for the different area:

- Absolute or relative length distribution of one or more years at the end of the model period
- CPUE values based on the total area for periods
- Estimates of escaping silver eel in weight and / or length at the end of the model period

## Model Outputs

Model outputs are eel population size, catch by fishermen, catch by anglers, catch by cormorants, mortality by other natural reasons, and silver eel escapement, all expressed as numbers per cohort and plotted on charts (Figure A3.2).



**Figure A3.2. Example output charts of the GEM application, presented for the River Elbe, Germany in 2005 – 2007.**

### Software implementation

The model was developed in MS-Excel® to facilitate its application to other river systems in Germany. It is easy to substitute assumptions concerning the stability of parameters over the total model period by yearly based estimates.

## A4. Scenario-based Model of Eel Production II (SMEP II)

### Authors

Walker, A.M., Apostolaki, P.A. & Pawson, M.G.

The original SMEP model was developed by Bark, A., Knights, B., Kirkwood, G., El-Hosaini, H. & E. Williams.

### References

Aprahamian, M. W., Walker, A. M., Williams, B., Bark, A. & Knights, B. (2007). On the application of models of European eel (*Anguilla anguilla*) production and escapement to the development of Eel Management Plans: the River Severn. *ICES Journal of Marine Science* 64, 1472-1482.

### Summary

SMEP II is a software package developed to model the dynamics and exploitation of eel populations. It is based on the model (SMEP) originally developed by Bark, Knights, Kirkwood, El-Hosaini & Williams for Defra project (CTG0102), further developed and tested during an Environment Agency-funded project and summarised in Aprahamian *et al.* (2007). The model works on the scale of a river basin and consists of 3 main components: a) a model that simulates both the biological characteristics of the eel population and a number of potential anthropogenic influences on that population (the population dynamics model). Biological processes modelled include growth, natural mortality, sexual differentiation, maturation (silvering) and movements within the river basin. Anthropogenic influences include environmental and habitat quality, fishing practices, barriers to movement, and stocking; b) a GIS tool that helps the user determine the spatial structure that they want to use for their calculations and prepare the input files for the population dynamics model to run; and c) a statistical model that is used to estimate some of the parameters of the population dynamics model.

### Introduction

The population dynamics model used in SMEP II is a length-based model that describes the dynamics of a population of eels for the duration of its stay in the river basin. The model is also sex-, life stage-, and area-specific and accounts for density-dependent effects and habitat structure and quality. The model does not include the dynamics of eels that have migrated from the river basin back to the spawning grounds (e.g. silver eels once they exit the river basin, or yellow eels moving back to saline waters (Tsukamoto and Arai, 2001). Since only partial simulation of the population's dynamics is possible (the salt-water phase of population's life is not simulated), processes such as recruitment cannot be modelled explicitly and, therefore, information about them needs to be provided externally (by the user).

The software is supplied with simple excel (.csv) files that allow the user to easily identify the options available for each of the processes simulated and choose those they want to use. The software is also supplied with a series of pre-set input files and folders that need to be in place for the program

to run (minimum set of inputs). If, for the options the user chooses, the model requires additional information to run, the user interface will provide directions on how to provide it.

The model can simulate the dynamics of the eel population under different assumptions about recruitment, environmental and habitat conditions, as well as initial conditions and the number of years over which the dynamics of the population will be simulated. The model projects the population forwards starting from a pre-defined initial condition (e.g. virgin conditions) (single projection) or can estimate the initial conditions and level of recruitment based on information about the status of the population at a specific year of the calculations (fitting the model to data, estimation of a single parameter). The statistical component of the software is used for the latter type of calculations. Options that allow the user to simulate fishing and impedance of movement or mortality associated with in-stream structures (barriers) are also available. The calculations are conducted assuming that all parameters are known without error (deterministic calculations). The only exception is when the model is fitted to data. In which case, the model assumes that there is some uncertainty around these data.

## Model processes

The following sections provide a detailed quantitative description of the formulae used to simulate the dynamics of an eel population and external factors that might affect it.

### Population numbers

The number of individuals,  $N$ , in the system will change over time due to natural mortality,  $M$ ; fishing mortality,  $F$ ; recruitment of new eels in the river,  $R$ ; and exit of silver eels from the system (moving to the sea). Each of these processes may affect eels of different length and/or life stage, and sex in different ways. The model uses three life stages to describe the population in the river: undifferentiated, yellow and silver eels - a further distinction is made between males and female yellow and silver eels. The model is length-based and as such, it assigns eels to different length classes and uses growth equations to determine how eels 'grow' from one length class to the next. Thus, at the beginning of each time step,  $\tau$ , the number of eels in length class,  $l$ , and stage,  $s$ , will be calculated taking into account all the processes that are relevant to each stage of eels life cycle (und=undifferentiated, y=yellow, sil = silver).

$$N_{l,s=und,\tau} = \sum_{l'=1}^l N_{l',s=und,\tau-1} \times G_{s,\tau-1}(l',l) \times e^{-(M_{l'}+F_{l',s})} \times (1 - D_{l',g=f+m,\tau-1}) + R_{l,\tau} \quad (1a)$$

$$N_{l,s=y,g,\tau} = \sum_{l'=1}^l (N_{l',s=y,g,\tau-1} \times G_{s,\tau-1}(l',l) \times e^{-(M_{l'}+F_{l'.s})} \times (1-V_{l',g,\tau-1}) + N_{l',s=und,\tau-1} \times G_{s,\tau-1}(l',l) \times e^{-(M_{l'}+F_{l'.s})} \times D_{l',g,\tau-1}) \quad (1b)$$

$$N_{l,s=sil,g,\tau} = \sum_{l'=1}^l (N_{l',s=y,g,\tau-1} \times G_s(l',l) \times e^{-(M_{l'}+F_{l'.s})} \times V_{l',g,t-1} + N_{l',s=sil,g,t-1} \times G_s(l',l) \times e^{-(M_{l'}+F_{l'.s})}) \quad (1c) \text{ where}$$

The definitions of the parameters shown above are as follows:

- $G_s(l',l)$  Growth matrix that gives the proportion of eels in length class,  $l'$ , and stage,  $s$ , to grow to length class,  $l$ , in one time step;
- $D_{l,g,t}$  The proportion of eels in length class,  $l$ , that become yellow of each gender,  $g$  (differentiation), at any time step;
- $V_{l,g,t}$  The proportion of yellow eels in length class,  $l$ , and gender,  $g$ , that becomes silver, in one time step.

The assumption used in the model for silver eels is that upon silvering they will leave the system at the next suitable time step. The model assumes that silver eel escapement takes place every year so that the silver eels calculated using formula (1c) will disappear from the system within a year from the time they become silver.

The sections below describe how the model simulates movement throughout the basin as well as the other processes included in our population dynamics model.

#### **Definition of eels density in a reach**

We have a limited understanding of how density affects the biology and dynamics of eels (though it appears to be an important force). The parameter input,  $B_{\max}$ , value represents the local biomass at and above which density-dependent effects are maximal for all the relevant processes (growth, sex differentiation, movement, mortality).

As mentioned above, the population dynamics model takes into account density effects when simulating the dynamics of eels. For the calculation, the density of eels in each reach is based upon their biomass rather than number. Expression of density as biomass per unit of space will not, however, provide enough information to allow comparison among the magnitude of density effects in each reach. This is because each reach might be able to sustain different levels of eel density, and the effects of density for two reaches that have the same density of eels might therefore be different. To resolve this problem, an additional parameter,  $C_r$ , has been introduced which is used to define the values of biomass above which density-dependent effects achieve their maximum values



for each reach. For each reach, the model calculates a relative biomass,  $\hat{B}_r(\tau)$ ; i.e. the biomass of the eels in a reach,  $B_r$ , divided by the reference biomass,  $C_r$  for the same reach. The model then uses the relative biomass as a proxy for eel density to calculate the effects of density on population dynamics. The user defines the reference biomass based on local knowledge or a default value.

### *Movement*

Area-specific saturation levels describe the effects of population density on processes such as sex differentiation, movement, mortality and growth.

SMEP II simulates a branching river channel topology, a feature that will characterise most natural situations where eel populations are found in rivers. The user provides information about the branching connectivity of reaches in the form of a matrix (after Lambert & Rochard, 2007).

The formula used to calculate the proportion of yellow or undifferentiated eels that move from one reach to an adjacent one follows the model used by Lambert & Rochard (2007). This describes movement that is driven by density and the ability of eels to cross obstacles and pass to adjacent reaches.

At each time step, the model calculates the number of eels that move from one reach to the next. The main assumption used for this simulation is that the movement of eels is affected by density levels in both reaches, the speed at which eels could travel, and their ability to pass any obstacles that they might encounter. In a single time step, an eel can only move from one reach to an adjacent one. The exception to this is for silver eels, which exit the system over one time step. The calculations used to simulate the movement of silver eels are described in a separate section below. So, for eels other than silver, the number of eels moving from one reach,  $r_1$ , to an adjacent reach,  $r_2$ , will be defined as follows:

$$\mathbf{N}(r_1 \rightarrow r_2) = N_{r_1} \times \text{potential to cross reach} \times \text{prob to pass barriers}(r_1, r_2) \times \text{density dependent tendency to move}(r_1, r_2) \quad (2)$$

The potential,  $\theta(r, s)$ , of eels in reach,  $r$ , and stage,  $s$ , to cross a reach is defined as the proportion of eels in the reach that are able to swim its length in one time step,  $\tau$ . Stage,  $s$ , could be undifferentiated or yellow. Therefore, this proportion is calculated if we know the (average) speed,  $u(s)$ , that eels at different stages could achieve and the length of each reach,  $\Lambda(r)$ :

$$\theta(r, s) = \frac{u(s) \times \tau}{\Lambda(r)} \quad (3)$$

*Programming-specific note:* Given that we want to know if all eels can cross the reach in one time step (or if not, what proportion), and also that eels can move only one reach at a time, any values of  $\theta(r, s)$  that are above 1 automatically mean that all eels could move outside the reach they occupy (i.e.  $\theta(r, s)$  is set equal to 1 when the result of the above calculation gives a value above 1).

Barriers and other obstacles could block or limit movement of eels from one reach to another. To account for this the model uses the probability to pass an obstacle,  $b(r_1, r_2)$  when it calculates the

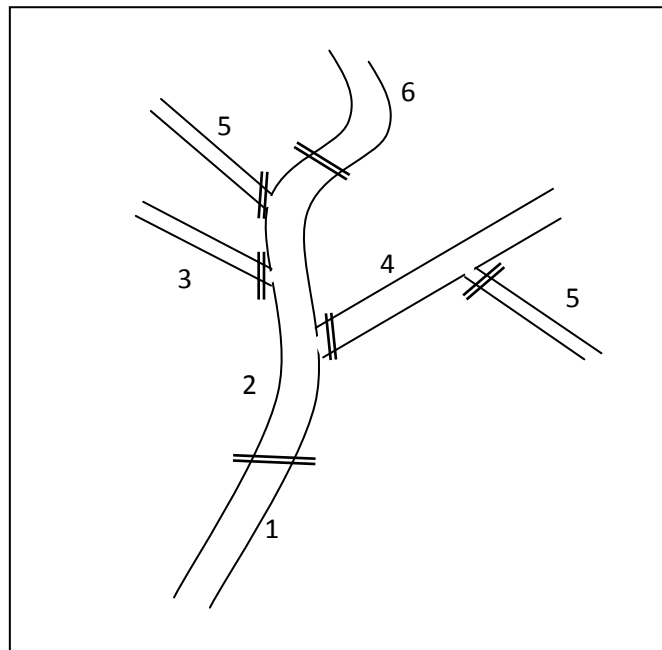
number of eels that move from reach,  $r_1$ , to an adjacent one,  $r_2$ . The user needs to provide this probability as an input to the model.

The movement of eels from one reach to an adjacent one will depend on the relative biomass  $\hat{B}_r(\tau)$  in each reach. The formula used to calculate the proportion of eels,  $\phi(r_1, r_2)$ , that will have the tendency to move from reach  $r_1$ , to reach  $r_2$ , as a result of differences in the relative biomass between the two reaches is described below (Whitehead, 2000; Lambert and Rochard, 2007):

$$\phi(r_1, r_2) = \frac{1}{\omega_{r_1}} \times \frac{d \hat{B}_{r_1}(\tau)}{C_{r_1} + d \hat{B}_{r_1}(\tau)} \times \frac{C_{r_2}}{C_{r_2} + d \hat{B}_{r_2}(\tau)} \quad (4)$$

Where:

$\omega_r$  is the number of reaches that are adjacent to reach,  $r$ . An example of the possible branching configurations is shown in Figure A4.1. In this example, reach 1 has only one adjacent reach while reach 2 has 5 adjacent reaches. Guidance on the rules that need to be followed when assigning numbers to the reaches is provided in the user manual.



**Figure A4.1. A possible branching configuration and selection of reaches when considering eel movements in a river**

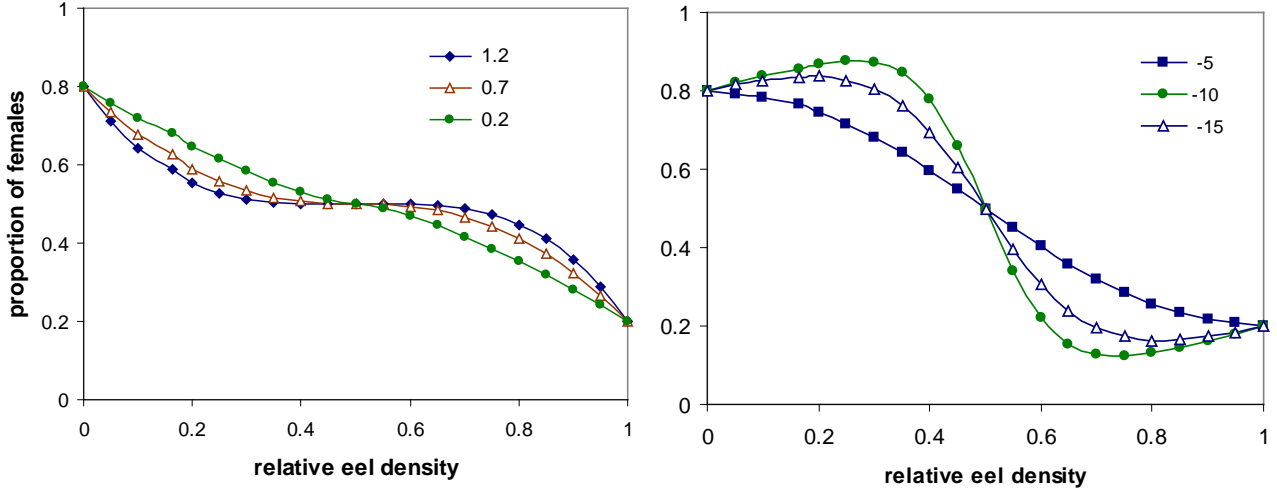
$d$  is a constant that describes the relative influence of the density levels in the reaches that the eel is moving ‘from’ and ‘to’, or the donor and recipient reaches. For very small values of  $d$ , the density level in the recipient reach does not affect the proportion of fish that move into it. The bigger the value of  $d$ , the more sensitive the simulation becomes to the relative difference between densities in both reaches, and the proportion of fish moving to a reach is affected less by the density levels in

the donor reach. In addition, for values of  $d$  that are big enough to be comparable to (or greater than) the reference biomass,  $C_r$ , the proportion of fish moving to a reach becomes almost insensitive to changes in density levels ( $\hat{B}_r$ ) once the density biomass in the donor reach exceeds that of the reference biomass.

The main assumption used for the simulation of the movement of silver eels is that they have a tendency to exit the system as soon as possible. Therefore, the number of silver eels that leave the system is determined by number of eel becoming silver in any particular model year, and the mortalities imposed by any turbines, fisheries, etc between the area in the river where the eel was when 'it' silvered and the downstream exit of the river basin.

### *Gender Differentiation*

The model assumes that all eels differentiate at the same length,  $L_D$ , but the proportion of the differentiating eels that become male or female depends on the relative biomass (density) of eels in their reach. Two different types of ogive curves can be chosen to describe that dependence. Figure A4.2 shows the two types of curves (Type I and Type II), and their mathematical descriptions are provided below (formulae 5 and 6). Each ogive curve is formed by two parts; for both ogive curve types, the coordinates of the inflection point (the point where the two parts of the curve connect) are always (0.5, 0.5). A shape parameter, called  $\rho$  for Type I curves and  $\lambda$  for Type II curves defines the shape of the curves. The maximum value that each of the two family of curves could take is equal to  $0.5 + \delta$  while the minimum value is equal to  $0.5 - \delta$ , where  $\delta$  is a constant and can take values between 0 and 0.5. Thus, the user could change the upper and lower value that the curves reach by modifying the value of the constant,  $\delta$ .



**Figure A4.2.** Types of curves that the model can use to describe the proportion of differentiating eels that become females at different levels of relative density. Left panel: Ogive type I, Right panel: Ogive type II. The numbers in the captions correspond to different values for the model parameter ( $\rho$  for Type I curves and  $\lambda$  for Type II curves) that determines the slope of the curves.

Type I

$$D_{l,g=f,\tau} = \begin{cases} 0.5 + \frac{\delta}{0.5^{2 \times \rho + 1}} \times (0.5 - \hat{B}_{s=und,\tau})^{2 \times \rho + 1}, & \text{if } \hat{B}_{s=und,\tau} \leq 1 \\ D_{l,g=f,\tau}(\hat{B} = 1) = 0.5 - \delta & \text{if } \hat{B}_{s=und,\tau} > 1 \end{cases} \quad (5)$$

Type II

$$D_{l,g=f,\tau} = \begin{cases} \frac{1}{1 + e^{-\lambda \times (\hat{B}_{s=und,\tau} - 0.5)}} + \left( |0.5 + \delta| - \frac{1}{1 + e^{0.5 \times \lambda}} \right) \times \frac{0.5 - \hat{B}_{s=und,\tau}}{0.5}, & \text{if } \hat{B}_{s=und,\tau} \leq 0.5 \\ \frac{1}{1 + e^{-\lambda \times (\hat{B}_{s=und,\tau} - 0.5)}} - \left( \frac{1}{1 + e^{-0.5 \times \lambda}} - |0.5 - \delta| \right) \times \frac{\hat{B}_{s=und,\tau} - 0.5}{0.5}, & \text{if } 1 \geq \hat{B}_{s=und,\tau} > 0.5 \\ D_{l,g=f,\tau}(\hat{B} = 1) = |0.5 - \delta| & \text{if } \hat{B}_{s=und,\tau} > 1 \end{cases} \quad (6)$$

Thus, for values of the relative density that are close to 0.5, ogive II results in far greater changes in the proportion of females for relatively smaller changes in density (relative biomass). On the

contrary, ogive I describes sharp changes in  $D_{l,g,t}$  for relatively smaller changes in density for values of the relative biomass that are close to 0 or 1.

A review of information on the proportion of undifferentiated eels that become males or females indicates that some females might be produced even at very high density levels. Equally, it is not clear if only males are produced at very low densities. Therefore, SMEP II includes a parameter that allows the user to specify the maximum and minimum proportion of females produced at extreme density conditions. Essentially, the types of curves are the same but the upper and lower limits can be modified depending on the situation that we want to simulate.

### Growth

The von Bertalanffy (VBF: Beverton & Holt, 1957) growth equation is often used to describe the growth of fish species. However, as there are indications that growth of eels might not be described well by a von Bertalanffy function, and to provide more flexibility in the simulation of eel's growth, the SMEP II provides three different sets of equations that can be used to simulate the growth of eels. These are a linear function, the VBF and the Schnute family of growth curves (Quinn and Deriso, 1999). All these functions can describe the length of an animal at a given age. As SMEP II is length-based, the information that is required by the model is the increase in the length of an eel of length,  $L$ , within a specified time period. So, all formulae were re-parameterized to give the increase in length in a time period rather than actual length-at-age. The formulae are shown below:

Linear model:

A linear model assumes that there is a constant increase,  $g$ , in the length of eels over time. Therefore, the increase in length,  $\Delta L$ , over a time period,  $\tau$ , will be:

$$\Delta L(L, \tau) = g \times \tau \quad (7)$$

VBF model:

$$\Delta L(L, \tau) = (L_{\max} - L) \times (1 - e^{-K\tau}), \quad (8)$$

Where  $L_{\max}$  is the maximum length that eels can attain and  $K$  is a parameter that determines the rate of increase towards  $L_{\max}$ .

Schnute model:

The Schnute model consists of four different formulae, each of which describes different growth behaviours. Although the linear and VBF models are sub-cases of the Schnute model, they have also been set up separately to make their use easier. The four equations are:

$$\Delta L(L, \tau) = \left[ L_1^\gamma + L^\gamma \times \chi_1 + \frac{(L_2^\gamma - L_1^\gamma + (L_1^\gamma \times \chi_2 - L_2^\gamma) \times \chi_1)}{1 - \chi_2} \right]^{1/\gamma} - L \quad (9a)$$

where  $\chi_1 = e^{-k\tau}$ ,  $\chi_2 = e^{-k(\tau_2-\tau_1)}$  and  $\gamma$  and  $k$  are constants that determine the type of curve that is used to describe growth. If both  $\gamma$  and  $k$  are not 0 then the above formula is used. Otherwise, one of the following three formulae applies.  $L_1$  and  $L_2$  are the lengths of eels at time  $\tau_1$  and  $\tau_2$ , respectively.

$$\Delta L(L, \tau) = L_1 \times e^{\frac{1-\chi_1 \cdot \ln \frac{L_2}{L_1} + \chi_1 \cdot \ln \frac{L}{L_1}}{1-\chi_2}} - L, \quad \gamma = 0 \quad (9b)$$

$$\Delta L(L, \tau) = \left[ L^\gamma + \frac{(L_2^\gamma - L_1^\gamma) \cdot \tau}{\tau_2 - \tau_1} \right]^{1/\gamma} - L, \quad k = 0 \quad (9c)$$

$$\Delta L(L, \tau) = L \times \left( e^{\frac{\ln(\frac{L_2}{L_1}) \cdot \tau}{\tau_2 - \tau_1}} - 1 \right), \quad \gamma = 0 \text{ and } k = 0 \quad (9d)$$

The SMEP II model allows the user to specify stage-specific parameters for the growth equation. If this option is chosen, the user will need to provide one set of parameter values for undifferentiated eels and another for differentiated eels, which may be specified for male and female yellow eels.

Each of the formulae described above calculate the increase in length for an eel of length,  $L$ , in time step,  $\tau$ . Each length class includes eels of different lengths, so the increase in their length in one time step will vary. In order to find the proportion of eels from one length class that grow to another, each length class is broken down into smaller sections (sub-classes), small enough that the increase in the length per time step of all eels in a sub-class is almost the same. Using the increase in length that corresponds to each sub-class, we can easily calculate the length-class to which eels will move in a time step.

### Natural Mortality

SMEP II provides the user with two means to describe natural mortality function: manual input of mortality rates for user-defined length classes, or selection of a mortality curve function.

In the absence of specific data for the river being studied, the length-based mortality rates are typically derived from the model of Bevacqua *et al.* (2010), based on fish length, typical eel densities, and mean annual water temperatures.

A more flexible means to describe natural mortality is to use a Weibull distribution,  $M$ , at length (De Leo & Gatto, 1995). In its simplest form, this formula has two parameters: the maximum length,  $L_{max}$ , and the Weibull parameter,  $\nu$ :

$$M(L) = \nu \cdot \left( \frac{L}{L_{max}} \right)^{\nu-1} e^{-\left( \frac{L}{L_{max}} \right)^\nu}, \quad L \geq 0 \quad (10a)$$

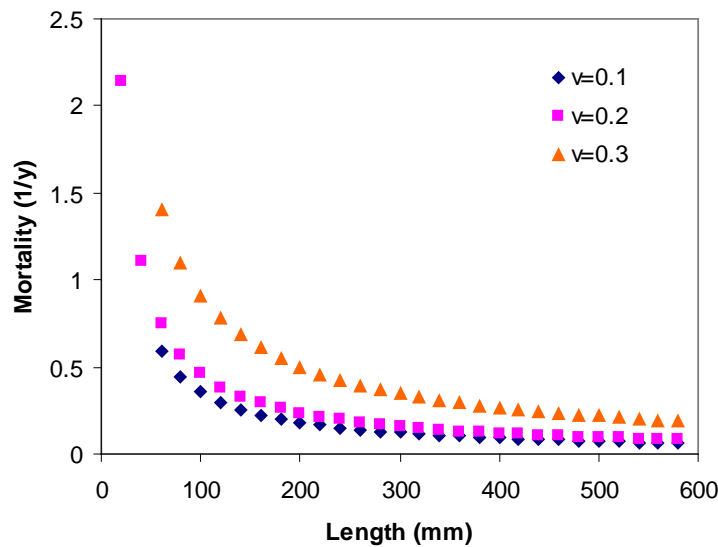
The formula above uses the length of eels to calculate the natural mortality that corresponds to their length. A second formulation of the Weibull function can also allow for density effects, as follows:

$$M(L, \hat{B}) = \nu' \left( \frac{L}{L_{\max}} \right)^{\nu'-1} e^{-\left( \frac{L}{L_{\max}} \right)^{\nu'}}, \quad L \geq 0 \quad (10b)$$

where

$$\nu' = \begin{cases} \hat{B} \cdot (\nu_{\max} - \nu_{\min}) + \nu_{\min}, & \hat{B} \leq 1 \\ \nu_{\max}, & \hat{B} > 1 \end{cases} \quad (10c)$$

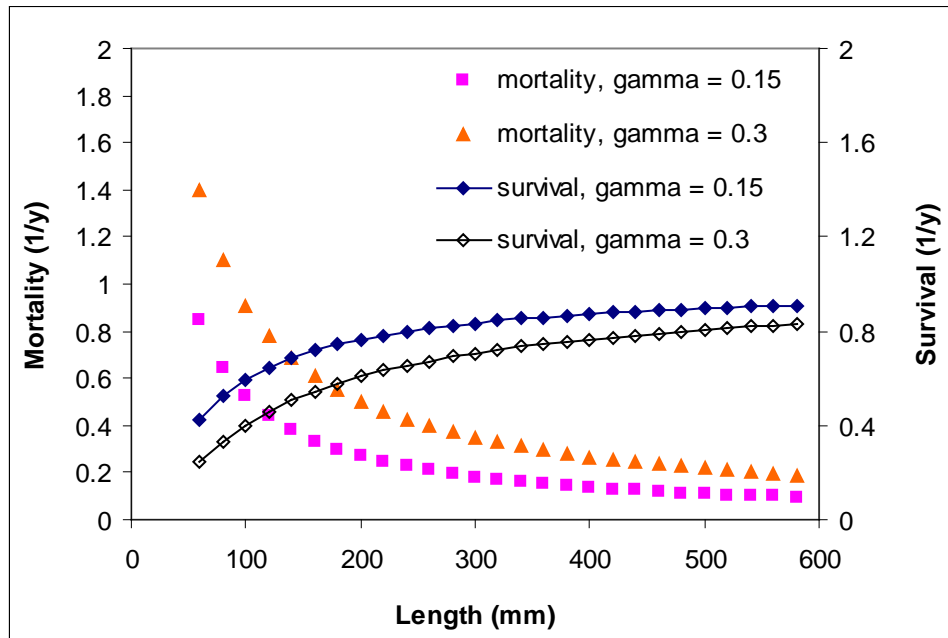
The model uses both parameterisations of the Weibull function: the density-independent formula is used to calculate the mortality of differentiated eels, while the density-dependent option is applied to calculate the mortality at length for undifferentiated eels. The changes in the shape of the mortality curve for different values of  $\nu$  and levels of eel density are shown in Figure A4.3.



**Figure 4.3. Weibull curves for 3 different values of the parameter  $\nu$ . If density effects are taken into account, and  $\nu_{\min}=0.1$  while  $\nu_{\max}=0.3$ , the curve that corresponds to  $\nu=0.2$  would give the values of  $M$  when the biomass of the relevant group (i.e. undifferentiated) was equal to 50% of its reference biomass.**

The formulae used to describe  $M$  give the mortality for eels of different length. As with the calculation of growth, these values are used to determine the value of  $M$  that corresponds to each length class. The Simpson method (Simpson & McGilchrist, 1980) is used to sum over the mortality values that correspond to the range of lengths included in each length class.

A graphical representation of the range of natural mortality values for each length class that seem reasonable according the literature is provided in Figure A4.4.



**Figure A4.4. Functions of natural mortality-at-length, and corresponding survival rates, for extreme mortality ‘gamma’ values. The two lines of coloured symbols for natural mortality define the range of values of natural mortality that are allowed for each length. Similarly, the two solid lines define the maximum and minimum values of mortality and survival for each eel length that SMEP II applies, depending on the levels of density of eels relative to the Critical Density.**

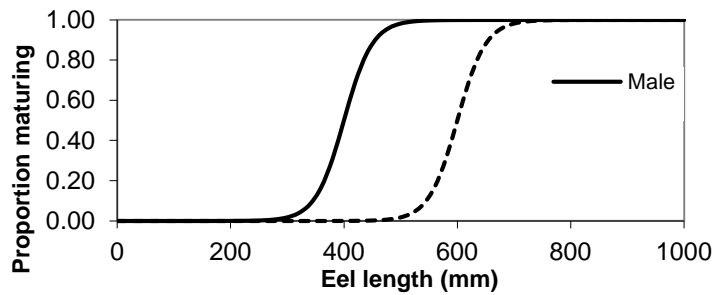
### Silvering

The model uses a logistic equation to describe the proportion of yellow eels that silver at each length:

$$V_{l,g,t} = \frac{1}{1 + e^{-\alpha_g \cdot (l - \eta_g)}}, \quad (11)$$

where  $\alpha_g$  and  $\eta_g$  are constants and are gender-specific. In this way, the model allows for gender-specific maturation (Figure A4.5). As with natural mortality, the Simpson formula is used to calculate the proportion of yellow females and males in each length class that will become silver.





**Figure A4.5. Single logistic functions for maturation at length for both males and females.**

### **Fishing**

Fishing can be described in SMEP II in two ways, depending on the available data: numbers caught by length class per gear type; or, numbers caught by stage (undifferentiated, yellow or silver) per gear type. All fishing data are related to reaches, seasons and years. Therefore, it is possible for the user to vary both the location and impact of fisheries, and simulate changes in the control of fisheries.

### **Recruitment**

Recruitment refers to the number of eels (usually glass eels) arriving at the mouth of a river basin each year. Due to the lack of knowledge regarding the oceanic phase of the eel’s life cycle and no observed spawner-recruit relationship, the model will only add recruitment if relevant information has been provided by the user. The information that the model needs in this case is the number of recruits, their length distribution (defined by the mean and standard deviation), and the upper and lower lengths of this distribution. The model then allocates the number of individuals across this length range, based on the assumption that recruit lengths are normally distributed between, and within, each length class.

### **Reference Biomass and Habitat Quality**

Each reach in a river basin is characterised by a reference biomass of eels that is used to calculate the relative biomass in each reach in order to determine the effects of density on population dynamics. To calculate the reference biomass per reach, the model multiplies the reference biomass density by the wetted area of that particular reach. Both the reference biomass density and wetted area are provided by the user as inputs to the model. The reference biomass,  $C_r$ , can then be multiplied by an environmental and habitat quality index to take account of annual environmental and habitat effects on the capacity (in terms of the biomass of eels it can sustain) of each reach. If the environmental and habitat quality index varies annually, the effects of density on the eel population in a given reach will also be expected to change from year to year, even if the density of eels in the reach does not.

### **Data Requirements**

In order to run a simulation, SMEP II must at least access information describing the scenario settings, the eel life history processes and the river basin in question. This information is the

minimum required in order for the model to predict potential escapement under 'pristine', constant conditions, if no information was available on the status of the local eel stock under such conditions.

Where data are available, either for historic or present conditions, these can also be applied to characterise the yellow eel population (in the past or present), impacts on escapement (e.g. fishing or turbines), inputs such as stocking events, and changes in the available area and quality of habitat. These additional data allow the user to set the model to simulate escapement under various conditions (past, present and future), and to alter the effects of impacts and inputs in order to examine their relative influence on escapement.

The model requires parameters to describe the eel production processes as defined above, i.e. growth and natural mortality rates, length at sex differentiation and silvering, and speed of movement throughout the river basin (see above for details). The user also defines the "*a* & *b*" constants for the length / weight relationship.

Annual recruitment is defined as a proportion of the maximum, which is also defined as numbers of eel and their length distribution.

Fishing impacts are defined according to the reach locations and years in which they occur, and the catches either as numbers of eel stage or of different length classes.

Stocking is described as the number and length of eels stocked, the reach where they are stocked and the year.

Variations in habitat quality are characterised in terms of their relative impact on the maximum biomass of eel that each reach can sustain. The user can either select the constant habitat condition such that all reaches are able to sustain the same area-specific biomass of eel (i.e. the carrying capacity: user defined), or the user can elect to specify reduced potential biomasses for reaches where less-than-ideal habitat quality is thought to impact on potential production of eel.

The spatial character of the river basin is described as a series of reaches, of known length and mean width. The branching structure of the river network is described using a connectivity matrix, detailing all of the connections of each reach to its neighbours. This matrix also describes the relative passability upstream between each reach and its neighbours, and the mortality associated with turbines for the eels moving downstream between each pair of reaches, where appropriate.

Where survey data are available to describe the eel stock at some point in time, these can be input to the model to allow the simulation to start from a known point. These eel observations are input as mean density, sex ratio (proportion females) and length frequency distribution, for each reach where surveys have been conducted. If data are not provided for any reach, the model assumes that this reach had no eels at the beginning of the simulation. Therefore, if eels were expected but had not been surveyed, the user should extrapolate from the nearest surveyed reach.

## Model outputs

SMEP II reports the results of simulations in a series of .csv files that provide, for each reach in every year: the density and biomass of undifferentiated, male and female yellow eels; numbers and weight of emigrating male and female silver eels; the proportion of females; and the numbers and weight of 'catch'.

End-of-run files provides summaries of density and biomass of undifferentiated, males and female yellow eels, biomass of male and female silver eels, and 'catch' (numbers and biomass) of undifferentiated, yellow and silver eels, and the length frequency of eels, stages and sexes in each reach.

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# Annex B. Detailed description of the model Constructed Reality for Eel Population Exploration (CREPE)

## Authors

P. Lambert, W. Dekker

## General features of the model

The aim of this model is not to simulate an actual study case but rather to test our knowledge of eel dynamics in river basins. The intention is to capture the main characteristics of the eel dynamics while escaping criticisms based on regional particularities. However, it is based on a review of the scientific literature on European eel, in order to be biologically meaningful and therefore to be acceptable to eel ecologists and managers.

The CREPE (Constructed Reality for Eel Population Exploration) model has been designed to incorporate present understanding of biological processes, management contexts, data availability and quality in river networks. Since this virtual approach provides the ideal data-rich situation, as all assessment/management scenarios are programmed into the data and therefore completely understood, the datasets produced by CREPE constitute benchmarks against which all models can be tested, both during POSE and in the future.

CREPE model was implemented in object-oriented language JAVA by using the modelling framework SimAquaLife (Dumoulin, 2007).

## Time

The time step is the season (4 time steps per year). Year starts with winter. The simulation duration lasts 150 years.

## River networks with lakes

### *Topology of the river networks*

The modelled space corresponds to a simple eel management unit (EMU) composed of five random river networks.

The networks were constructed using a diffusion-limited aggregation model (Masek & Turcotte, 1993). The initial grid was based on a 200\*200 square cell lattice. A cell is supposed to represent an area of 1 km<sup>2</sup>. Five river mouths were randomly located on the south side of the grid. Random walkers were introduced randomly on that grid and each two-dimensional random walk proceeded until the walker found a drainage network on which to accrete. This model with a headward growth of river networks generates patterns remarkably similar to actual drainages, with statistical features (frequency-order bifurcation ratio, stream length-order network fractal dimension) which agree with actual networks (Masek & Turcotte 1993). It also reproduces the spatial interaction of river network in terms of size and therefore captures part of the complexity of an EMU with several basins.

### Drainage areas

We modified the algorithm to also simulate drainage areas. Drainage is the area of land upstream of the lowermost point of the reach and local drainage is the area of drainage specific to the reach, excluding the drainage from reaches further upstream. The catchment area corresponds to drainage area at the river network outlet.

The surrounding cells of a new accreted cell become the local drainage area of that cell. The drainage area of a cell ( $da$ ) is calculated by adding the local drainage areas of all the upstream cells.

### Creation of lakes

The global abundance of surface-water bodies in our constructed catchments was based on the Pareto distribution fitted by Downing *et al.* (2006) on a worldwide database. In this analysis the number of ponds and lakes  $> 0.001 \text{ km}^2$  in the world  $N_t$  is estimated to be in the neighbourhood of 304 million. It is possible to calculate the density (number per  $10^6 \text{ km}^2$ ) of water bodies within the size range  $[A_{\min}, A_{\max}[$

$$d_{[A_{\min}, A_{\max}[} = \frac{-N_t k^c (A_{\max}^{-c} - A_{\min}^{-c})}{A_{\text{earth}}}$$

where  $k = 0.001$  the location parameter,  $c = 1.06079$  the shape parameter of the Pareto distribution and  $A_{\text{earth}} = 1.5 \cdot 10^2 (10^6 \text{ km}^2)$ , the earth's continental land surface. The mean size of water bodies within the size range  $[A_{\min}, A_{\max}[$  is equal to:

$$\bar{A}_{[A_{\min}, A_{\max}[} = c \frac{A_{\max}^c A_{\min} - A_{\max} A_{\min}^c}{(c-1)(A_{\max}^c - A_{\min}^c)}$$

Table B1 presents the results for different constructed eel management units. Since the unit cell is  $1 \text{ km}^2$ , we only simulate water bodies with mean size equal or greater than  $2 \text{ km}^2$ .

**Table B1. Distribution of water bodies according to their area based on Downing et al. (2006) analysis for three eel management units of different sizes.**

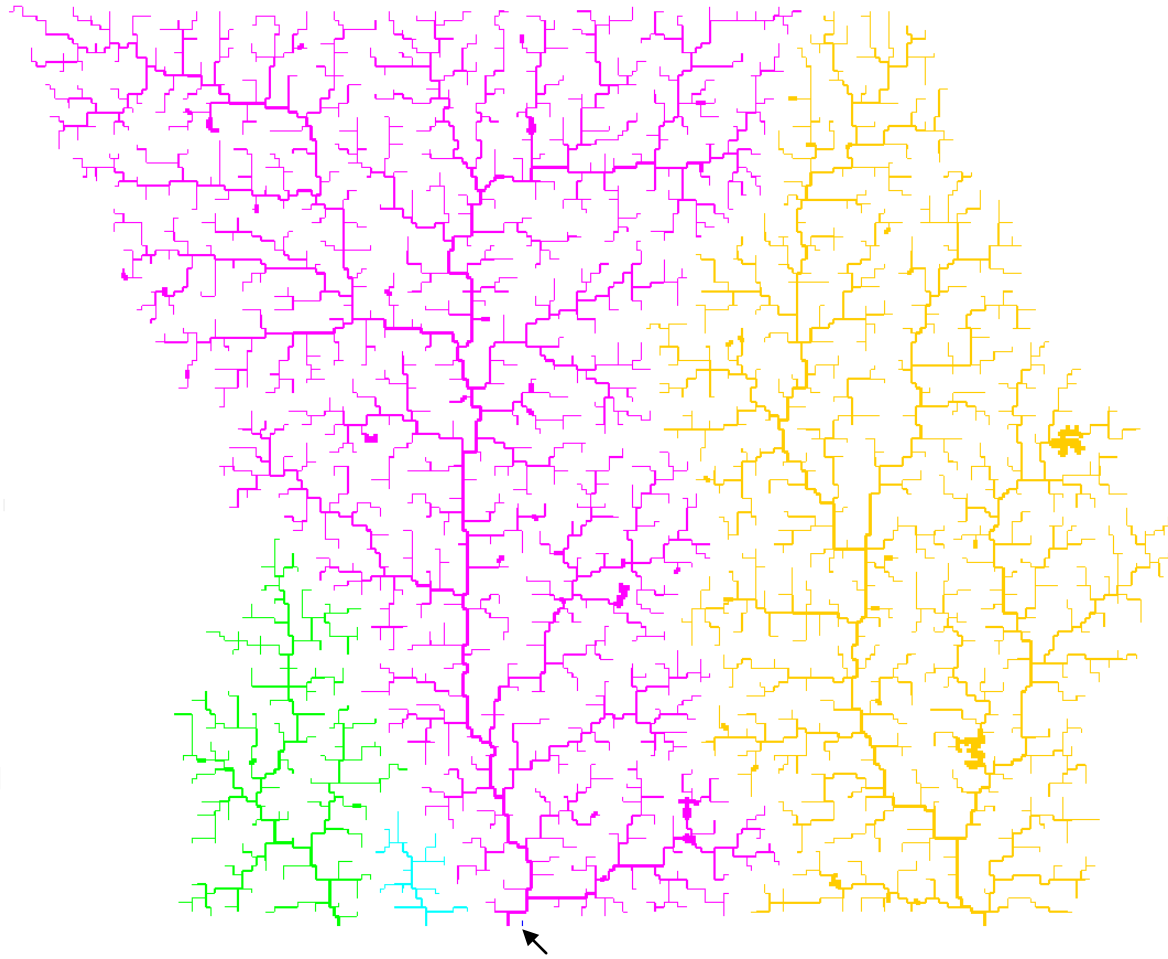
$A_{\min}$ (km <sup>2</sup> )	$A_{\max}$ (km <sup>2</sup> )	$\bar{A}$ (km <sup>2</sup> )	density (nb per 10 <sup>6</sup> km <sup>2</sup> )	Size of constructed eel management unit (nb 1km <sup>2</sup> cells)		
				10 x 10	100 x 100	200 x 200
0.001	0.01	0.0025	1 849 480	185	18 495	73 979
0.01	0.1	0.025	160 790	16	1 608	6 432
0.1	1	0.25	13 979	1	140	559
1	5	2.0	1 090	0	11	44
5	10	7	126	0	1	5
10	20	14	60	0	1	2
20	100	40	45	0	0	2
100	1000	250	9	0	0	0

The principle of lake creation is to randomly draw a seed within the river cells and to transform upstream river cells into lake cells until reaching the designated water body size. To this end, it is necessary to first simplify the river network (transform cells with Shreve index of 1 to drainage zones) to avoid connections between river reaches when creating lakes.

***From surface network to linear network***

Each cell is transformed into a river reach, connected with a single downstream reach (except for the outlet which has no downstream reach), with one or several upstream reaches (several in case of confluence) and in case of water bodies with lateral reaches. Reach length  $\lambda_{reach}$  is fixed at 1 km. The drainage areas become attributes of the reach and no more spatial localisation are taken into account (except for screen display).

Figure B1 presents the five virtual river networks used in this study. It was created on a 200 x 200 grid, 9670 zones correspond to rivers and 231 to lakes, 30 099 to drainage zones. The five basins have 1, 96, 740, 3789 and 5275 reaches, respectively.



**Figure B1.** Virtual river networks used in CREPE simulation (the arrow indicates the 1 reach river network).

## Reach characteristics

### *Distance to the sea, to the source, Shreve index and Strahler order*

Based on the river network topology, the distance to the sea (corresponding to the lowermost point of the most downstream reach), distance to the source (i.e. the top of the most upstream reach), Shreve index (i.e. the number of sources located upstream of a given reach) and Strahler order (Strahler 1957) are calculated.

### *Wetted width of a reach*

The width  $W$  (in m) of a reach is calculated with the formula proposed by McGinnity *et al.* (in press):

$$W = 10^{0.22734 da^{0.20045} sh^{0.25939} - 1}$$

where  $da$  is the drainage area (in ha) of the reach and  $sh$  is the Shreve index.

### *Tidal and saline intrusion lengths*

Combining Prandle's equations (2004), the length of tidal intrusion in an estuary,  $L_{tide}$  (m), is expressed with the following equation:

$$L_{tide} = 2460(12.8)^{5/4} \left( \frac{\alpha}{\xi} \right)^{1/2} Q^{1/2}$$

where  $\alpha$  is the lateral slope of an assumed triangular cross section of the estuary,  $Q$  is the river flow ( $\text{m}^3 \text{s}^{-1}$ ) and  $\xi$  is the tidal elevation amplitude (m). Therefore, the length of tidal intrusion is a function of the square root of the river flow if tidal elevation amplitude and lateral slope are constant in a given eel management unit.

Considering discharge to be proportional to catchment area  $A$ , we used the following relationship:

$$L_{tide} = a_{tide} A^{1/2}$$

Based on French data in EurEFish 1.0 (Nicolas *et al.*, 2010), where  $a_{tide}$  is evaluated as 0.62 with  $A$  in  $\text{km}^2$  and  $L$  in km. Note that a linear model on log transformed data gives a power of 0.33, instead 0.5.

Again combining Prandle's equation (2004), we obtained a theoretical expression for the length of saline intrusion:

$$L_{saline} = \frac{2(12.8)^2 \alpha^{4/5}}{fU_T U_0} Q^{4/5}$$

where  $U_T$  is the tidal velocity amplitude,  $U_0$  is the residual (riverine) velocity,  $f$  is the bed friction coefficient and  $\alpha$ , as previously, is the lateral slope of an assumed triangular cross section of the estuary.

Considering that discharge is proportional to catchment area, we used the following relationship:

$$L_{saline} = a_{saline} A^{4/5}$$

Based on French data in EurEFish 1.0,  $a_{saline}$  is evaluated as 0.10, with  $A$  in  $\text{km}^2$  and  $L$  in km. Note that a linear model on log transformed data gives a power of 0.21, far from 0.8 for the saline intrusion and a negative power for the ratio.

These figures are calculated for the main stream of the estuary. We considered the ratio of these lengths to the distance to the source, to also simulate tides in the tributaries.

A reach  $r_i$  is influenced by the tide if:

$$\frac{d_i^{sea}}{d_i^{source}} < \frac{L_{tide}}{d_0^{source}}$$



and influenced by the salted tide if:

$$\frac{d_i^{sea}}{d_i^{source}} < \frac{L_{saline}}{d_0^{source}}$$

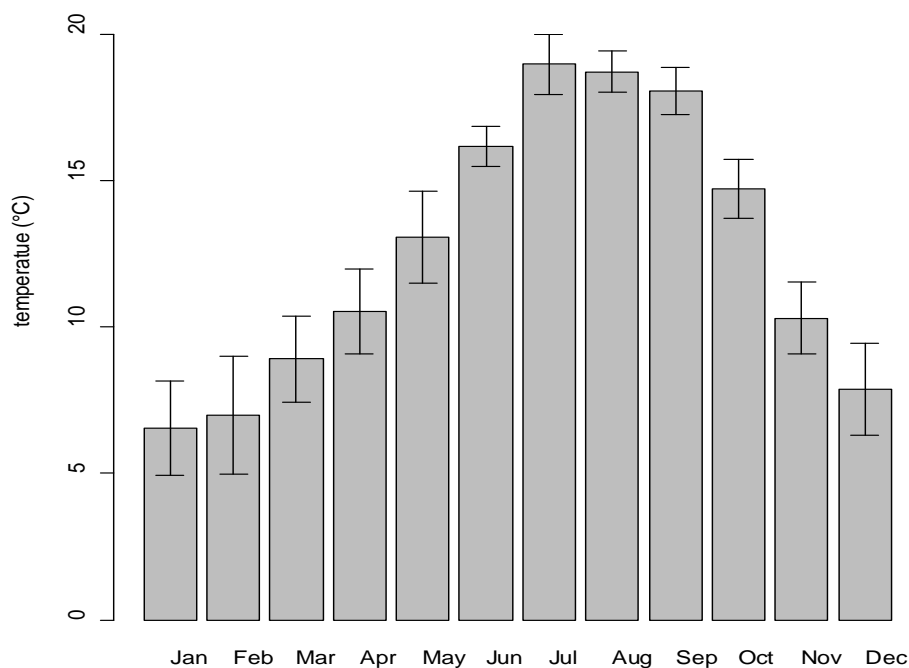
where  $d_i^{sea}$  is the distance to the sea for the reach  $i$ ,  $d_i^{source}$  and  $d_0^{source}$  are the distances to the source for the reach  $i$  and the outlet, respectively.

### Carrying capacity

In the present version, the carrying capacity  $cc_i$  of the reach  $i$  is arbitrary fixed at  $50 \text{ kg ha}^{-1}$  for all reaches. This value corresponds to a mean value of observed biomass in a catchment and not to maximum biomass measured in downstream reaches close to  $250 \text{ kg ha}^{-1}$ . This parameter is used in the “mortality of the standing stock” and “sex determinism” processes.

### Temperature time series

In order to take into account annual variations in biological processes due to varying environmental conditions, we simulated a monthly time series of temperature (air temperature as proxy for water temperature: Erickson & Stefan 2000). To this end, we extract an air temperature pattern, i.e. mean and standard deviation for each month, (Figure B2) for a localisation (grid identifier : 25474) extract from the CRU TS 2.1 (Mitchell & Jones 2005) data set of monthly observed climate for the period 1901-2000.



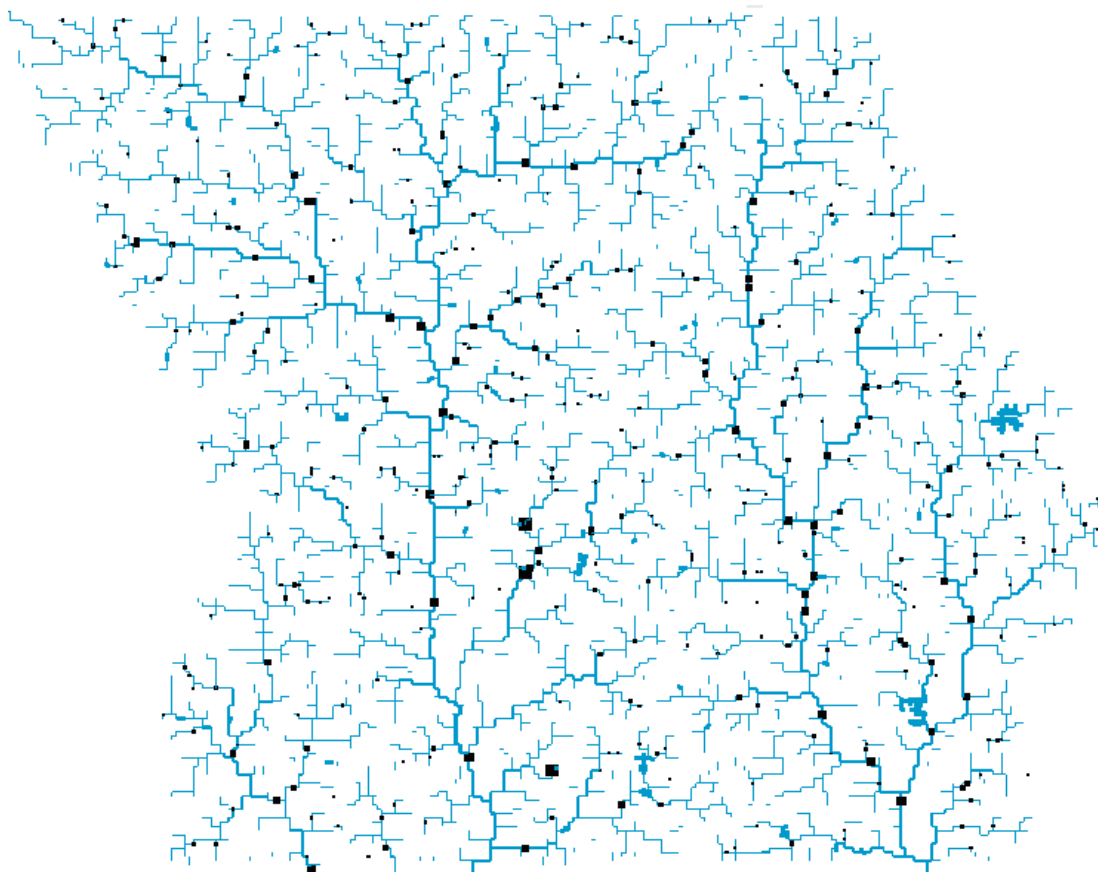
**Figure B2. Pattern of monthly temperatures (mean and standard deviation) used in time series simulation to provide some seasonal and inter-annual variation in environmental conditions**

For every winter (start of the year), we drew monthly temperatures from a normal distribution with mean and standard deviation from the values of the considered month in the temperature pattern (Figure B2). We added an autocorrelation with the previous month to avoid sharp changes in temperature.

### Obstacles to migration

An obstacle is characterized by probabilities of an eel passing downstream or upstream, and the mortality induced when fish pass downstream or upstream. Each obstacle is associated with a list of records which summarize the fish counting at the dam.

We fixed the density of obstacles at 0.01 obstacles per km<sup>2</sup>, i.e. 400 obstacles were created in the simulated eel management unit. The locations were chosen randomly among the river reaches (Figure B3). We considered that 25% of these obstacles are equipped with turbines and then induced mortality during the downstream passage.



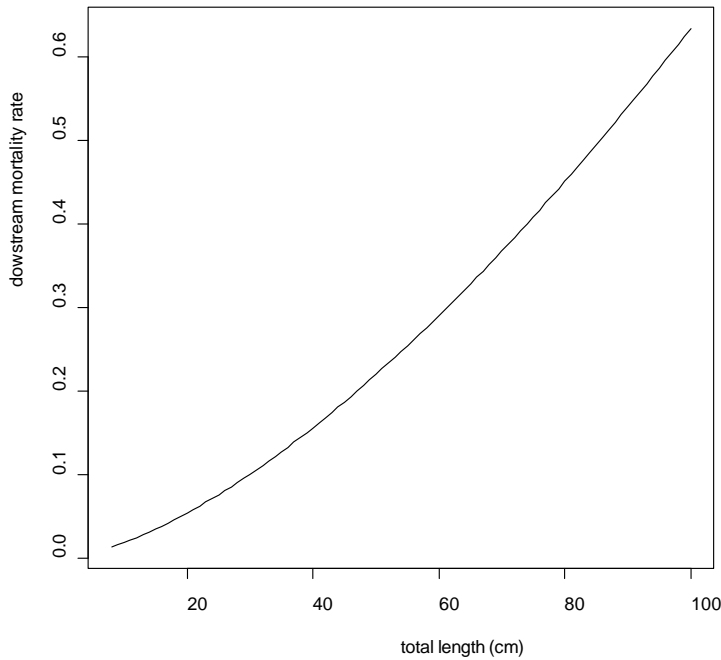
**Figure B3. Location of dams (black squares) in the river networks**

The probability of upstream and downstream passage, and mortality rates were drawn at random from normal distributions. Gomes and Larinier (2008) provided the following formulae for

downstream mortality in dams with turbines  $0.0467L^{1.53}D_t^{-0.48}R_t^{0.6}$  where  $L$  is the length of eel (m),  $D_t$  the turbine diameter (m) and  $R_t$  the rotation speed of the turbine (rpm). We simplified this into a power relationship  $a_{down}L^{1.53}$ . Based on the Gomes and Larinier (2008) dataset of  $D_t$  and  $R_t$ ,  $a_{down}$  is distributed following a normal distribution  $N(0.63, 0.38)$ . We considered that half of river discharge flowed through the turbine. Therefore, the downstream mortality  $m_{down,k}$  of obstacle  $k$ , is:

$$m_{down,k} = \frac{a_{down,k}}{2} L^{1.53}$$

as illustrated in Figure B4.



**Figure B4. Evolution of downstream mortality rates according to fish length in a dam with turbine**

No data are available for the upstream mortality  $m_{up,k}$  in dams with or without turbines. Therefore, we postulated the following relationship for both types of obstacles:

$$m_{up,k} = a_{up,k} L$$

with  $a_{up,k}$  drawn from a normal distribution  $N(0.10, 0.05)$ .

Probabilities of passage were simply drawn from normal distributions:  $N(0.70, 0.15)$  for upstream passage ( $p_{up,k}$ ), and  $N(0.90, 0.5)$  for downstream passage ( $p_{down,k}$ ), without taking variation

according to fish length. To avoid any computational difficulties, mortality rates and passage probabilities were forced to range between 0 and 1.

The impact of obstacles is simulated during the “glass eel arrival”, “moving” and “catadromous migration” processes. Information on fish that pass the dam during these processes is recorded in the obstacle records, which are available to the “obstacle scientist”.

## Fishermen

At the start of the model run, fishermen divide up the river basin amongst themselves so that no spatial overlap between fishermen occurs, i.e. each reach is fished by only one fisherman. A fisherman can fish several reaches but only within one catchment.

Equal class intervals of sea distance are defined after having fixed the number of fishermen in the longest river network. Then a fisherman fishes all the reaches corresponding to a sea distance class in a catchment. With 20 fishermen in the longest river network (default value), 48 fishermen are created in the simulated EMU.

### Fishing effort

Each fisherman performs three métiers targeting glass eels, yellow eels and silver eels, respectively. He operates three fishing efforts  $f_{glass}$ ,  $f_{yellow}$  and  $f_{silver}$  in non-defined arbitrary units (for example corresponding to a number of fishing days or a filtered volume per reach for glass eel, or to numbers of nets per reach for yellow and silver eels per reach). The impact of each fishing action is spatially restricted to the reach where the gears are set, i.e. only the eels within that reach are vulnerable to that gear. Note that  $f_{glass}$  quickly becomes null for fishermen who do not fish in tidal zone since they are not able to catch any glass eel.

### Fishing mortality

Glass eel and silver eel fishing mortalities are simulated during the corresponding movement processes: “glass eel arrival” and “catadromous migration”. The yellow eel fishing mortalities are simulated during the specific “mortality” process of yellow eels.

### Cost and benefit of fishing

The costs of fishing,  $cost_{glass}$ ,  $cost_{yellow}$  and  $cost_{silver}$  are considered to be strictly proportional to the fishing efforts,

$$cost_i = f_i priceEffort_i$$

where  $i$ , taking *glass*, *yellow* or *silver*, corresponds to the métiers and  $priceEffort_i$  the unit cost of one métier effort. There will be fixed costs for any commercial fishing operation, for having a boat and gears. Lowering their usage in part-time fishing, however, will probably lengthen the number of years these fixed assets can be used. Consequently, all costs become proportional to the fishing efforts.

$priceEffort_{yellow}$  and  $priceEffort_{silver}$  were both fixed at 100 €/year (Personal communication with Sipke Bootsma, commercial fisherman, Hindeloopen, the Netherlands).  $priceEffort_{glass}$  was fixed at 175 €/year (pers. comm. Gérard Castelnau, Cemagref, Bordeaux, France).

The income of fishing was based on a fixed price of 366 €/kg for glass eel ( $priceEel_{glass}$ ), 5.75 €/kg for yellow eel ( $priceEel_{yellow}$ ) and 5.0 €/kg for silver eel ( $priceEel_{silver}$ ). The first two figures corresponded to the mean prices between 2000 and 2010 (ICES 2011), and the silver eel value was fixed at a little cheaper than the yellow eel price (after Moriarty & Dekker 1997; Dekker 2004).

### **Optimising fishing efforts**

Each fisherman keeps track of his fishing efforts and profits in short-term and long-term memories for the three metiers. The short-term memory corresponds to the last value or to the average of the last three values. The long-term memory is equal to the average of the last 30 values. This choice was based on frequent conversations with many fishermen across Europe, who clearly distinguished between the current and a few (3) preceding years, while contrasting this to their father's situation, one generation (30 years) ago. The length of short-term memory for the yellow eel fishery was 3 years, whereas only the latter value was used for glass eel and silver eel fisheries. In effect, and in contrast to the yellow eel fishery, over-exploiting migrating eels (glass eels or silver eels) in a particular year has no consequence for the fisherman in the next year. Glass eel and silver eel fishermen around Europe know that perfectly well, and therefore optimise their effort on the spot, rather than on historical information. These memories were implemented by simply using a list of the last 30 figures.

Whenever the short-term profits exceed the long-term profits for a metier, the new fishing effort  $f_i$  is set equal in the short-term memory; otherwise  $f_i$  is set to the fishing effort in the long-term memory. A multiplicative lognormal variability  $e^{N(0,\sigma_f)}$  is then added, since both short-term and long-term memories deviate.  $\sigma_f$  was fixed at 0.1. If the profits of a metier are negative or null for 3 consecutive years, the fisherman stops practising this metier.

During the model populating phase, the fishing efforts were kept constant at a low level for the first 10 years to avoid closing fisheries when eel abundances were still low. After that period, the fishing efforts were optimised until the model reached quasi-stable efforts.

## **Eel Biology**

### **Artifact**

Eels are implemented as super-individuals (Rose *et al.*, 1993; Scheffer *et al.*, 1995), with the amount of individuals within a super-eel having the same biological characteristics and the same behaviours, except that mortality affects only a proportion of them at the same time.

### **Age**

The oceanic phase of the life cycle is not included in the model. The continental age of super-eel  $i$  is noted  $A_i$ . The birth season is fixed at spring.

$A_i = 0$  corresponds to the age from time at estuarine arrival to the first birthday,  $A_i = 1$  corresponds to the age during the second year in continental waters.

### **Length and weight relationship**

We used an allometric relationship between length (in cm) and weight (in gram):

$$W_i = aL_i^b$$

Parameters  $a$  and  $b$  were averaged over the relationships found in literature with a geometric mean for  $a$  and an arithmetic mean  $b$  (as  $W$  and  $L$  relationship is linear in  $\log(a)$  and  $b$ ) (Table B2).

**Table B2. Review of length-weight relationships from published studies, based on collections of undifferentiated (Und.), male and female eels.**

Hydrosystem	Stage	Sex	$a$	$b$	Reference
Ffraw River	yellow	Und. & male	$5.41 \cdot 10^{-4}$	3.3730	(Sinha & Jones 1967)
		female	$13.80 \cdot 10^{-4}$	3.1054	
Rhyd-hir River	yellow	Und. & male	$10.83 \cdot 10^{-4}$	3.1920	
		female	$18.47 \cdot 10^{-4}$	2.9916	
Glaslyn River	yellow	Und. & male	$7.139 \cdot 10^{-4}$	2.2948	
		female	$19.03 \cdot 10^{-4}$	3.0238	
Mediterranean lagoon	yellow	Und. male	$5.25 \cdot 10^{-4}$	3.37	(Melià <i>et al.</i> , 2006)
		female	$11.50 \cdot 10^{-4}$	3.15	
		female	$8.71 \cdot 10^{-4}$	3.22	
	silver	mixed	$11.91 \cdot 10^{-4}$	3.15	
Rhine River	yellow	mixed	$11.47 \cdot 10^{-4}$	3.11	(Yahyaoui <i>et al.</i> , 2004)
Swedish west coast	yellow	mixed	$5.90 \cdot 10^{-4}$	3.21	(Svedäng, 1999)
Mediterranean lagoon	yellow	male	$5.926 \cdot 10^{-4}$	3.28	(Ximenes, 1986)
Atlantic marsh	yellow	mixed	$8.116 \cdot 10^{-4}$	3.19	(Lee, 1979)
Mediterranean lagoon	yellow	mixed	$3.516 \cdot 10^{-4}$	3.37	(De Leo & Gatto, 1995)
Mediterranean lagoon		mixed	$2.70 \cdot 10^{-4}$	3.46	
Aquaculture	yellow	mixed	$1.85 \cdot 10^{-4}$	3.63	(Knights, 1982)
Grand Lieu Lake	yellow	mixed	$7.19 \cdot 10^{-4}$	3.24	(Adam & Elie, 1993)
Mean			$9.1842 \cdot 10^{-4}$	3.1813	

## Biological processes

### Glass eel arrival

The time series of glass eel recruitment in the simulated EMU is split into several time periods:

1. the initial phase for populating and stabilizing the model (50 years);
2. a period with a constant level of glass eel recruitment (25 years);
3. a period of decreasing recruitment – the ‘crash’ (30 years);
4. another period of stable recruitment (20 years);

5. a period of increasing recruitment (25 years).

The nominal annual recruitment before the crash, i.e. in periods 1 and 2, was set at 10 million glass eels. However, year-to-year variation in glass eel recruitment was introduced into the time series by applying a log-normal stochasticity with standard deviation of 0.3, corresponding to the year-to-year variation in the observed time series of glass eel recruitment in Europe outside North Sea between 1980 and 2000 (ICES, 2011).

The decline in recruitment during the ‘crash’ is simulated according to an exponential coefficient of decrease set to 0.0961, based on the observed glass eel recruitment data in Europe except North Sea during 1980-2000 (ICES, 2011). The increase in recruitment, the ‘recovery’, is simulated according to an exponential coefficient of increase fixed at half the coefficient of decrease.

Proportions of 1000 super-eels were added every winter to each basin in proportion to their catchment area. Each super-eel within a year-class could have an equal or stochastic (lognormal distribution) amount of eels.

#### *Glass eel movement*

The first settlements of glass eels (first locations of super eels) are randomly drawn amongst the tidal reaches of the catchment in order to simulate an upstream oriented migration in the tidal zone with a random settlement.

On the way to settlement, the super eels experience the impact of obstacles and the glass eel fishery in each reach they pass.

#### *Glass eel natural mortality*

The glass eel natural mortality coefficient  $M_{glass}$  is fixed at 4.81 year<sup>-1</sup> as estimated in Lambert (2008). This figure leads to a mortality rate of 70% during a migration season (a quarter of the year). To ensure compatibility with glass eel fishing mortality, the natural mortality is converted into km<sup>-1</sup> by considering the length of the path to the settlement destination.

#### *Glass eel fishing mortality*

The glass eel fishing mortality coefficient in the reach  $j$  equals  $F_{glass,j} = q_{glass} f_{glass,j}$  where  $q_{glass}$  is the glass eel fishery catchability and  $f_{glass,i}$  is the effort exerted by the fisherman who fishes in reach  $j$ . The catchability  $q_{glass}$  was fixed at 0.08 km<sup>-1</sup> effort unit<sup>-1</sup> in order to ensure an exploitation rate (ratio between total catch and glass eel abundance) around 20% corresponding to the minimum value for an open-estuary fishery (Beaulaton and Briand 2007).

The amount of eels within a super-eel  $i$  located in reach  $j$  decreases by a number  $N_{dead,i}$  drawn at random from a multinomial distribution with parameters  $N_i$  the number of eels in super-eel  $i$ , and probability:

$$1 - e^{-(F_{glass,i,j} + M_{i,j})\lambda_{reach}}$$

where  $\lambda_{reach}$  is the reach length (1km). Of those, the number of glass eel caught by a fisherman equals:

$$C_{glass,i} = \frac{F_{glass,j}}{F_{glass,j} + M_{i,j}} N_{dead,i}$$

## Impact of obstacles

At each obstacle  $k$  encountered by an eel, a Bernoulli distribution with probability  $p_{up,k}$  determines whether the eel successfully passes upstream or not. Otherwise, the amount of eels within a super-eel  $i$  is reduced by a number drawn at random from a multinomial distribution with parameters for the number of eels in the super eel  $N_i$  and probability  $m_{up,k}$ .

The number of eels passing the obstacle  $N_i(1 - m_{up,k})$  is also recorded in the record list of the obstacle.

## Growth

The annual growth rate of a super eel combines an intrinsic growth rate, an age effect, a year effect (through the sum of monthly temperatures above 13°C) and a habitat effect (Daverat *et al.*, submitted). The intrinsic growth rate and age effect are specific to each individual (Yokouchi *et al.*, in prep). The annual growth rate  $gr_i(t, h)$  for the super-eel  $i$  located in reach  $j$  during the year  $t$  is calculated by the following equation:

$$gr_{i,j}(t) = e^{a_{0,i}} e^{a_{1,i}A_i} e^{a_2 \sum T(t)>13} e^{a_3 \frac{DSea_j}{DSea_j + DSource_j}} e^{a_{4,j}}$$

where  $a_{0,i}$  is the intrinsic growth rate of the super-eel,  $a_{1,i}$  is the coefficient related to age and specific to one super-eel,  $a_2$  is the coefficient (the same for all the super-individuals) related to the annual sum of monthly temperatures above 13°C,  $a_3$  is the coefficient related to the relative distance between sea and source of the reach  $j$  and  $a_{4,j}$  is for the habitat type of reach  $j$ .

Based on the findings of Daverat *et al.* and Yokouchi *et al.*, we fixed:

$$a_{0,i} \square N(1.560, 0.25),$$

$$a_{1,i} \square N(-0.067, 0.03),$$

$$a_2 = 0.0076 \text{ and}$$

$$a_3 = -0.2642$$



Daverat *et al.* (submitted) described habitat according to depth, relative distance to the sea and salinity. The growth rate of eels in a lake is probably lower than in a nearby river because the home ranges in lakes are much larger than in rivers (Minns, 1995). However, there are very few data on which to model such relative growth rates, so in our approach we simply consider:

$$a_{4,j} = \begin{cases} -1.11 & \text{for lake} \\ 0.09 & \text{for salted habitat} \\ 1 & \text{otherwise} \end{cases}$$

In this case, the growth rate of eels is one third less in lake and 10% higher in saline habitats than the rate of eels in rivers. The growth process in saline habitats near the sea is illustrated in Figure B5.

We assumed no differences in growth rates between undifferentiated, male and female eels, and that there was no density dependent effect on growth rates.

The body length of each super-eel starts at  $L_0 = 7\text{cm}$ , and increases each spring by the growth rate by using the previous formulae.

—

**Figure B5. Simulated length for fish in saline habitat near the sea (relative distance 5%) with a constant year effect ( $\sum_{T(t)>13} = 23$ ). The horizontal red line indicates the mean length threshold for a female to silver**

## Standing stock mortality

### Natural mortality

From Bevacqua *et al.* (2011) (Table B3), we assumed an exponential mortality coefficient  $M_i$  (year<sup>-1</sup>) for the super-eel  $i$  scaled with body mass  $W_i$  (g) and annual average of water temperature  $T$  (K):

$$M_i = a_M e^{-E/kT} W_i^b$$

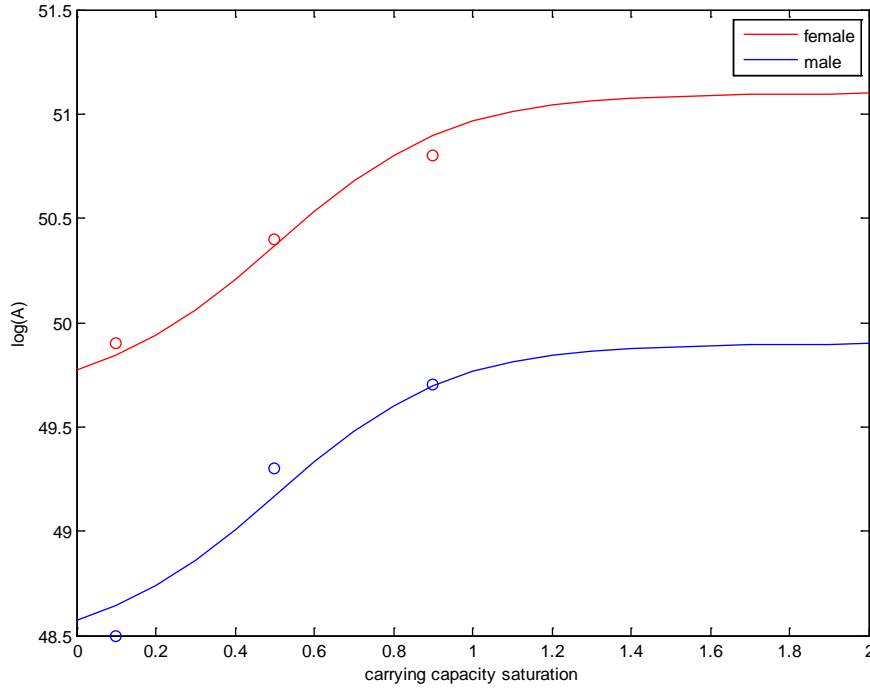
where  $a_M$  is a proportionality coefficient,  $e^{-E/kT}$  is the Boltzmann–Arrhenius factor,  $k$  is the Boltzmann constant ( $8.62 \cdot 10^{-5}$  eV K<sup>-1</sup>),  $E$  (eV) is the activation energy and  $b$  is an allometric exponent.

**Table B3. Coefficient of mortality parameters found by Bevacqua *et al.* (2010). The values presented in parentheses for males and females are the 90% Confidence Intervals for  $E$  and  $b$ .**

Parameter	Density	Female	Male
$E$		1.24 (0.80 – 1.72)	1.22 (.72 to 1.72)
$\log(a_M)$	High	50.8	49.7
	Intermediate	50.4	49.3
	Low	49.9	48.5
$b$		-0.46 (-0.56 to -0.36)	

We fitted a logistic function to predict  $a_M$  supposing that high density corresponds to 90% of carrying capacity saturation, intermediate density to 50% and low density to 10% based on the following formula, the results of which are presented in Figure B6.

$$\log(a_M) = \frac{1.46}{1 + e^{-4.55(\text{sat} - .05)}} + \begin{cases} 49.64 \text{ for females} \\ 48.44 \text{ for males} \end{cases}$$



**Figure B6.** Putative evolution of  $\log(a_m)$  for female (red line) and male (blue line) yellow eels, according to carrying capacity saturation. The three open circles from left to right in each colour correspond to estimates of  $\log(a_m)$  found by Bevacqua *et al.* (2011) for low, intermediate and high densities, respectively.

Bevacqua *et al.* (2011) did not provide any information for undifferentiated eels. Therefore, we supposed a higher value of 50.0 for the minimum of  $\log(a_M)$ .

#### Yellow eel fishing mortality

The fishing mortality coefficient in the reach  $j$  is:

$$F_{yellow,j} = q_{yellow} f_{yellow,j} \delta_{yellow}(L_i)$$

where  $q_{yellow}$  is the yellow eel fishery catchability,  $f_{yellow,j}$  is the effort exerted by the fisherman who fishes in reach  $j$ , and  $\delta_{yellow}(L_i)$  indicates the length-selectivity of the yellow eel fishing gear (the same for all yellow eel fishermen).

Beaulaton (2008) simulated the selectivity curve of an eel pot with a logistic function:

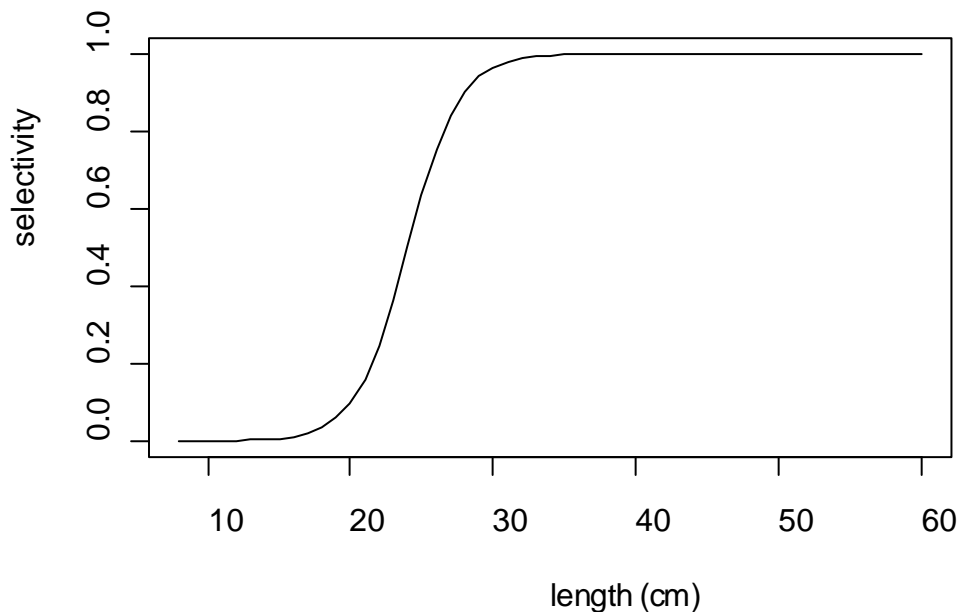
$$\delta_{yellow}(L) = \frac{1}{1 + e^{\frac{\kappa_{yellow} - L}{\zeta_{yellow}}}}$$

where  $\kappa_{yellow}$ , the length at 50% selective, varied from 19 to 32 cm (median 24 cm) and,  $\zeta_{yellow}$ , the slope of the logistic function varied between 1.6 and 2.7 cm (median 1.8) in the Gironde. Bevacqua *et al.* (2009) proposed a logistic function based on the trunk section of the eel to simulate fyke net selectivity. With the average length-weight relationship above, the following formula is obtained:

$$\delta_{yellow}(L) = \frac{1}{1 + e^{-e^{-1.65-0.6ms} (9.1842 \cdot 10^{-2} L^{2.1813} - e^{3.26+0.09ms})}}$$

where  $ms$  is stretched-mesh size in mm.

In CREPE, we used the eel pot selectivity with Beaulaton's median parameters, which are similar to the selectivity of a 15mm fyke net (Figure B7).



**Figure B7. Selectivities of an eel pot used in Gironde (Beaulaton, 2008) and a fyke net of 15mm stretched-mesh size (Bevacqua et al., 2009) for yellow eel.**

The parameter  $q_{yellow}$  was tuned so that the fishing yield (in biomass) from the yellow eel fishery was approximately twice that of the silver eel fishery (Dekker, 2000), resulting in  $q_{yellow} = 0.045 \text{ year}^{-1}$  for 20 fishers.

### Population number

The amount of eels within a super-eel  $i$  located in reach  $j$  decreases each season by a number  $N_{dead,i}$  drawn at random from a multinomial distribution with parameters  $N_i$  the number of eels in super-eel  $i$ , and probability:

$$1 - e^{-(F_{yellow,i,j} + M_{i,j})\Delta_{season}}$$

where  $\Delta_{season}$  is the duration of a season (0.25 year). Of those, the number of yellow eels caught by a fisherman equals:

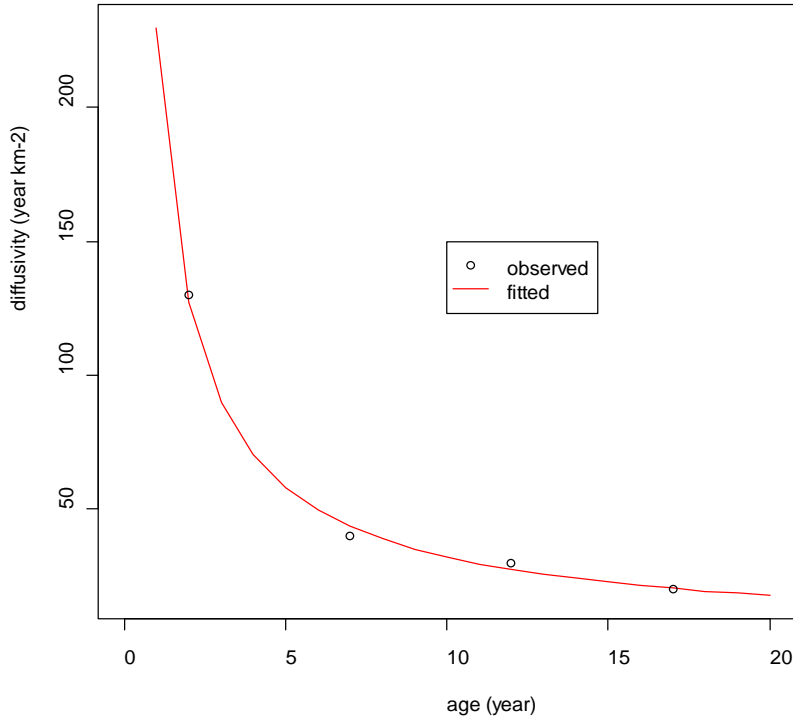
$$C_{yellow,i} = \frac{F_{yellow,i,j}}{F_{yellow,i,j} + M_{i,j}} N_{dead,i}$$

These catches are reported in the fisherman's catch records (list).

## Movements

### Diffusive movement

In CREPE, yellow eel movements (upstream or downstream) occur during spring. After glass eel arrival (which implicitly includes an advective component within the tidal reaches), displacements are simulated as non-orientated movements among contiguous reaches. These movements are characterised by a diffusivity coefficient  $\delta$  which depends on eel age  $a$ . This diffusivity coefficient is represented by a power function  $\delta = 230a^{-0.8544}$ , after Ibbotson *et al.* (2002) (Figure B8).



**Figure B8. Evolution of diffusivity according to age (the observed values correspond to those reported by Ibbotson et al. (2002)).**

Fish migration is impaired in this river catchment by several weirs and sluices (White & Knights, 1997). Therefore, the diffusivity at age 0 was increased to  $1150 \text{ km}^2 \text{ year}^{-1}$  to simulate a free dispersal ( $\delta = 1150a^{-0.8544}$ ). With this modification the root mean square of fish location is changed from 15 km to 56 km.

A diffusion process can be simulated with a 'random walk' (DeAngelis & Yeh, 1984; Okubo & Levin, 2001) where the number of basic displacements before age  $A_i$  is related to diffusivity by the following equation:

$$N_{moving}(A_i) = \frac{2A_i\delta(A_i)}{\lambda_{reach}^2}$$

where  $\lambda_{reach}$  is the reach length (in CREPE this length is the same for all reaches). Therefore the number of basic displacements at age  $A_i$  is:

$$n_{moving}(A_i) = \frac{2}{\lambda_{reach}^2} (A_i\delta(A_i) - ((A_i - 1)\delta(A_i - 1)))$$

$$n_{moving}(A_i) = \frac{2300}{\lambda_{reach}^2} \left( A_i^{0.1456} - (A_i - 1)^{0.1456} \right)$$

With a 1 km reach length, 65% of basic displacements occur during the first year of life (Table B4). At that age, a third of the fish are located 15 km upstream of their arrival reach and 5% of individuals have already exceeded the 40th km of migration.

**Table B4. Number of simulated eel movements in any spring according to age.**

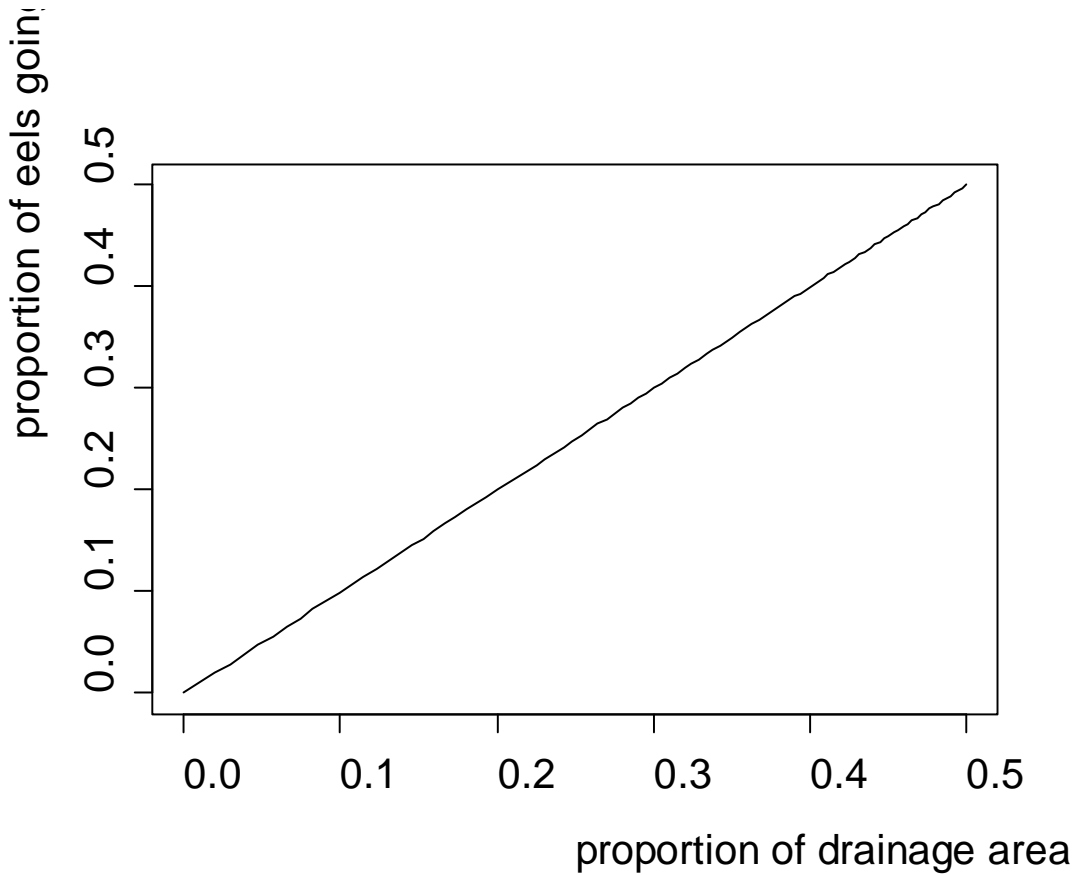
Age (y)	Eel displacements	Age (y)	Eel displacements
1	460	11	9
2	49	12	8
3	31	13	8
4	23	14	7
5	19	15	7
6	16	16	6
7	14	17	6
8	12	18	6
9	11	19	6
10	10	20	5

The direction of a basic displacement is randomly chosen between upstream, downstream or lateral in the case of lakes. In case of several lateral reaches evolving from the reach that the eel occupies before the movement, the destination is randomly chosen.

In the case of there being several upstream reaches evolving from the reach that the eel occupies before the movement, the destination is drawn according to probabilities:

$$p_i = \frac{da_i^c}{\sum_j da_j^c}$$

where  $da_i$  is the drainage area of reach  $i$ , and  $c$  is a parameter to modulate bifurcation between mainstream and tributary ( $c < 1$  gives priority to small tributaries,  $c > 1$  to the mainstream, Figure B9). To ensure the presence of eel in enough electro-fishing operations (since electro-fishing stations are located in shallow reaches and therefore in tributaries),  $c$  was fixed at 0.5.



**Figure B9. Evolution of the proportion of eels moving into a tributary according to relative drainage area from tributary for 3 values of the parameter  $c$ .**

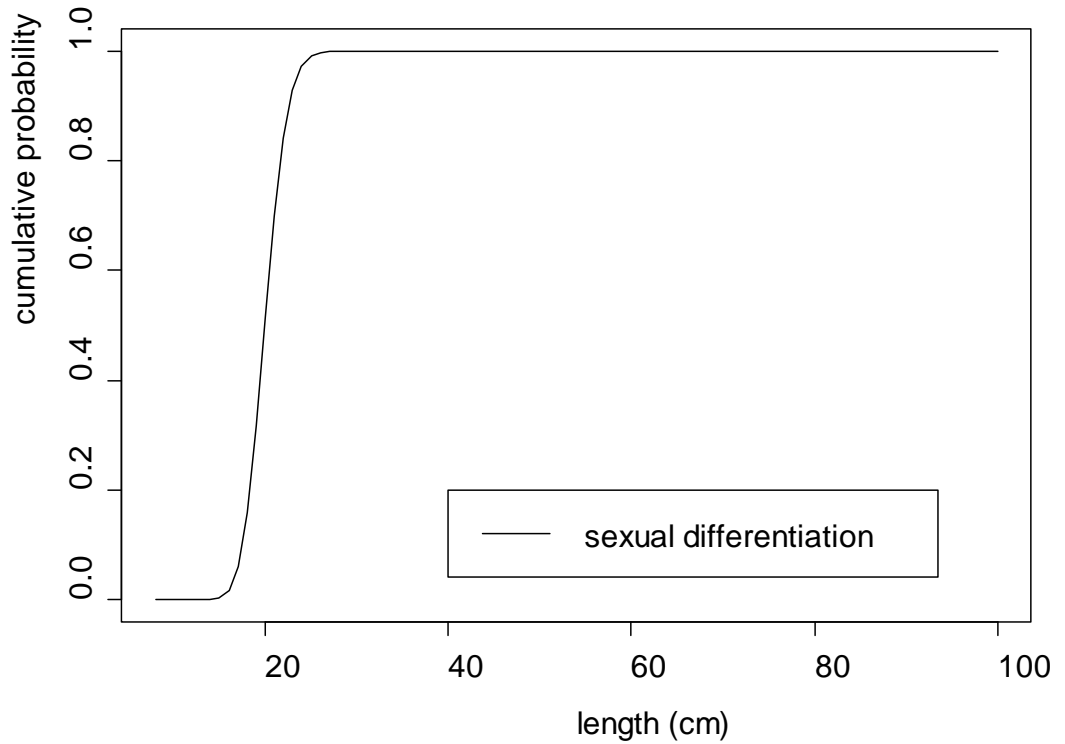
### **Impact of obstacles**

The impact of obstacles is simulated after computation of the destination reach, i.e. after the simulation of all the basic displacements, to avoid the possibility of the eel passing over the obstacle several times, as can be induced by a strictly Brownian movement.

At each obstacle  $k$  encountered, a Bernoulli distribution with probability  $P_{up,k}$  for upstream movement or probability  $P_{down,k}$  for downstream movement determines the passing success in the appropriate direction. When the probability is less than the critical value the movement stops. When passage occurs, the amount of eels within a super-eel  $j$  is reduced by a number drawn at random in a multinomial distribution with parameters for the number of eels in the super-eel  $N_i$  and probability  $m_{up,k}$  or  $m_{down,k}$  depending on the direction of movement.

The number of eel passing the obstacle  $N_i(1-m_{up,k})$  or  $N_i(1-m_{down,k})$  is also recorded in the record list of the obstacle.





### Sexual differentiation and sex determinism

We considered that sexual differentiation, as the change from undifferentiated to male or female eel, depends on length but not age (Melià *et al.*, 2006) and takes place during the summer. We assumed that the proportion of fish that have differentiated before length  $L$  follows a gamma cumulative distribution function of length  $\Gamma(L | \mu_{sd}, \sigma_{sd})$  with mean  $\mu_{sd}$  and standard deviation  $\sigma_{sd}$ . Melià *et al.*, (2006) estimated a length at differentiation of 20.4 cm with bootstrapping standard deviation of 3.8 cm. We used these values for  $\mu_{sd}$  and  $\sigma_{sd}$  (Figure B10).

The conditional probability that a super-eel differentiates in the summer  $t$  (at length  $L_i(t)$ ) where it was undifferentiated the previous summer  $t-1$  (when its length was  $L_i(t-1)$ ), equals:

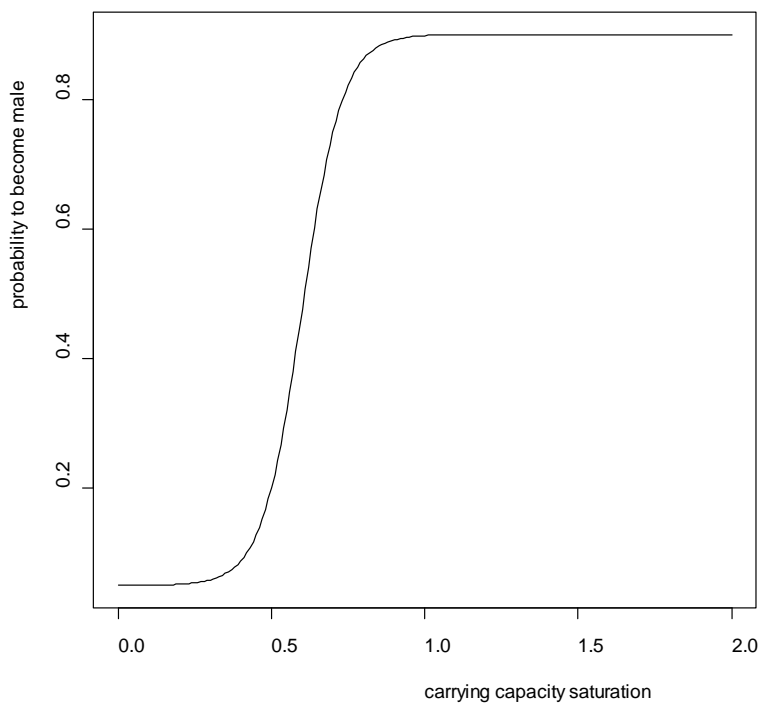
$$\gamma_{sd}(t) = 1 - \frac{1 - \Gamma(L_i(t) | \mu_{sd}, \sigma_{sd})}{1 - \Gamma(L_i(t-1) | \mu_{sd}, \sigma_{sd})}$$

Figure B10. Probability distributions for an eel of given length to be differentiated

Sex determinism in European eels, i.e. becoming male or female, is considered to occur during development in response to environmental factors (Wiberg 1983). Classically, female production is supposed to be favoured at low population densities (Davey and Jellyman 2005). The probability for a super-eel  $i$  located in reach  $j$  that differentiates during summer  $t$  to become male was calculated with a logistic function according to the relative saturation of the reach's carrying capacity  $sat_j(t)$ :

$$pm_i(t) = pm_{\min} + \frac{pm_{\max} - pm_{\min}}{1 + e^{-\log(99) \frac{sat_j(t) - s_{50}}{s_{99} - s_{50}}}}$$

where  $pm_{\min}$  and  $pm_{\max}$  are minimum and maximum probabilities that the eel will become male,  $s_{50}$  is the saturation level that produces  $\frac{pm_{\min} + pm_{\max}}{2}$ , and  $s_{99}$  is the saturation level that produces  $0.99(pm_{\min} + pm_{\max})$  of males amongst the differentiating eels. Without any quantitative information, we fixed  $pm_{\min}$  to 5%,  $pm_{\max}$  to 95%,  $s_{50}$  to 60% and  $s_{99}$  to 90%. The shape of this probability with respect to the relative saturation of the carrying capacity of the reach is shown in Figure B11.



**Figure B11. Evolution of the probability of an undifferentiated eel becoming male according the saturation of carrying capacity of the reach**

Note that  $S_{99} = +\infty$ ,  $pm_{\min} = 0$ ,  $pm_{\max} = 1$  and  $\mu_{sd} = 0$  are equivalent to simulating a genotypic determinism (i.e. at or before conception) with an equilibrated recruitment sex ratio.

## Silvering

Silvering, as a change from yellow stage to silver stage, is supposed to depend only on length (Vollestad, 1992) and takes place during winter (Durif *et al.*, 2005). We assumed that the probability that an eel silvers before length  $L$  follows a gamma cumulative distribution function of length with mean and standard deviation different between the sexes:

$$\begin{aligned} & \text{females } \Gamma(L - L_{sf \min} \mid \mu_{sf}, \sigma_{sf}) \text{ and,} \\ & \text{males } \Gamma(L - L_{sm \min} \mid \mu_{sm}, \sigma_{sm}). \end{aligned}$$

The parameter for  $L_{s \min}$  truncates the silvering at a minimum length in order to prevent the formula resulting in silver super-eel that are too short compared to reality.

As for sexual differentiation, the probability that a female super-eel  $i$  silvers during the winter  $t$  (at length  $L_i(t)$ ), given that it was still yellow the previous winter  $t-1$  (when its length was  $L_i(t-1)$ ) equals:

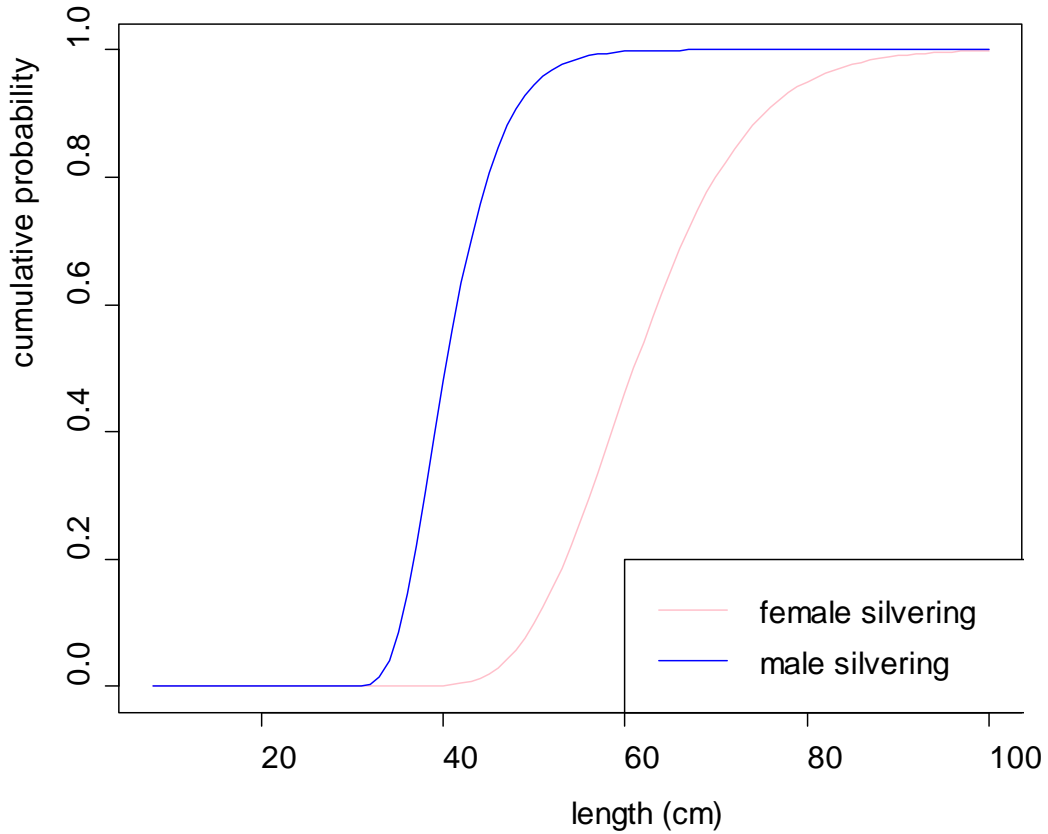
$$\gamma_{sf}(t) = 1 - \frac{1 - \Gamma(L_i(t) - L_{sf \min} \mid \mu_{sf}, \sigma_{sf})}{1 - \Gamma(L_i(t-1) - L_{sf \min} \mid \mu_{sf}, \sigma_{sf})}$$

For a male super-eel, the probability is:

$$\gamma_{sm}(t) = 1 - \frac{1 - \Gamma(L_i(t) - L_{sm \min} \mid \mu_{sm}, \sigma_{sm})}{1 - \Gamma(L_i(t-1) - L_{sm \min} \mid \mu_{sm}, \sigma_{sm})}$$

We fixed  $L_{sf \min}$  and  $L_{sm \min}$  to 30 cm since silver eels below this length are rare (Vollestad, 1992).

We fixed the mean silvering length parameter of female and male eels,  $\mu_{sf}$  and  $\mu_{sm}$ , to the mean length of silver eels reported by Vollestad (1992), i.e. 62 cm and 41 cm, respectively. We arbitrarily fixed  $\sigma_{sf}$  and  $\sigma_{sm}$  to 10 and 5 cm to take into account the higher variability in length at maturity observed for females (Vollestad, 1992; Bevacqua *et al.*, 2006) (Figure B12).



**Figure B12. Probability distributions for female (pink line) and male (blue line) eels of given length to silver**

#### *Catadromous migration*

At the end of winter, silver super-eels emigrate immediately to the outlet of the catchment, then are removed from the population and counted in the main output of the model. On their way out, they experience the impact of any silver eel fishery and / or obstacles in each reach they pass through.

#### *Silver eel fishery mortality*

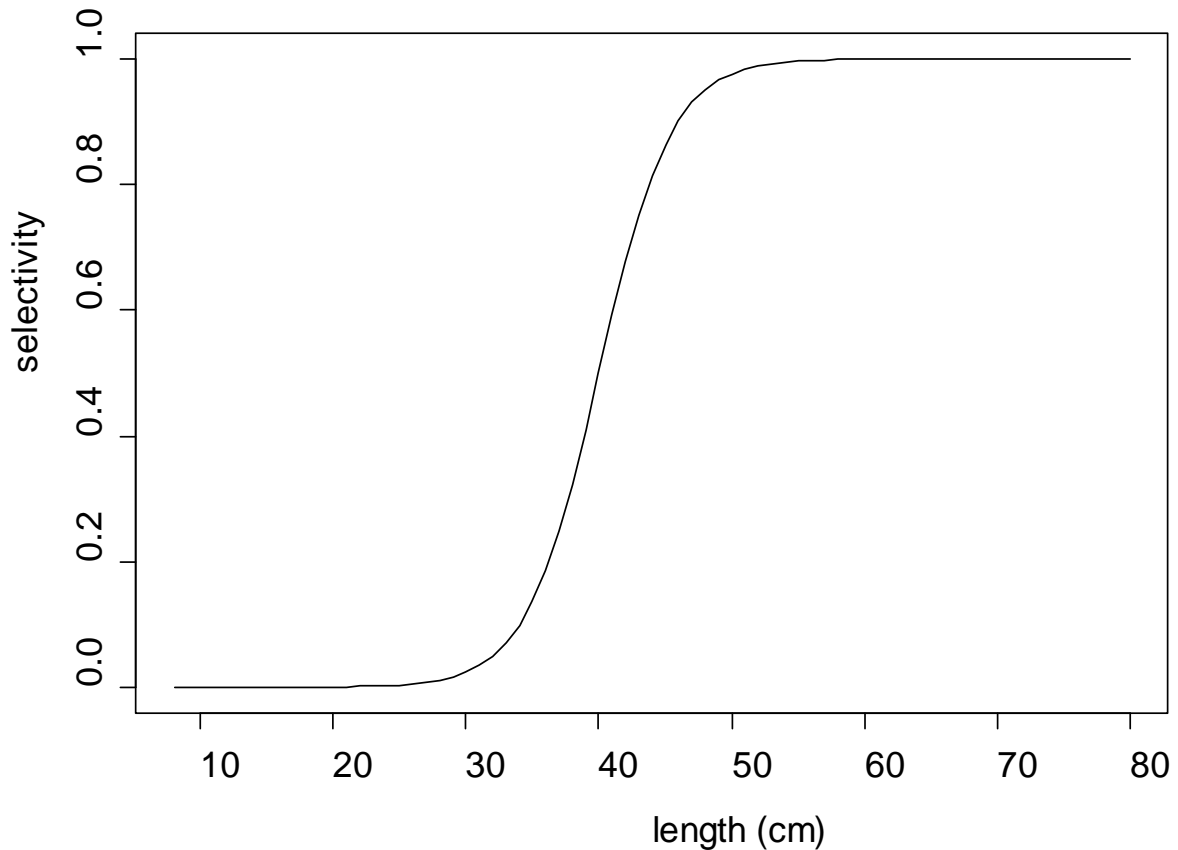
The fishing mortality coefficient in the reach  $j$  for the super-eel of length  $L_i$  equals:

$$F_{silver,i,j} = q_{silver} f_{silver,j} \delta_{silver} (L_i)$$

where  $q_{silver}$  is the silver eel fishery catchability,  $f_{silver,j}$  is the effort exerted by the fisherman who fishes in reach  $j$ , and  $\delta_{silver} (L_j)$  (explored further below) indicates the length-selectivity of the silver eel fishing gear (the same for all silver eel fishermen).

$$\delta_{silver} (L_i) = \frac{1}{1 + e^{\frac{\kappa_{silver} - L_i}{\zeta_{silver}}}}$$

with  $\kappa_{silver} = 40 \text{ cm}$  and  $\zeta_{silver} = 2.4 \text{ cm}$  (B13). This corresponds to the average of the minimum legal sizes listed in Table 6 of Moriarty (1996), i.e. 50% selective at 40 cm, and 25% selective at 37 cm.



**Figure B13. Selectivity curves for silver eel fisheries, after Moriarty (1996).**

The catchability for the silver eel fishery,  $q_{silver}$  was tuned so that the silver eel escapement (in biomass) was approximately half the silver eel fishing yield (Dekker 2000) - resulting in  $q_{silver} = 0.008 \text{ km}^{-1}$  for 20 fishers.

During catadromous migration, natural mortality is set at  $M_{silver} = 0.0 \text{ km}^{-1}$ .

Note that  $F_{glass}$ ,  $M_{glass}$ ,  $F_{silver}$  and  $M_{silver}$  for the silver eel quantify the mortalities according to the distance of the river they have to pass on their way to the sea, and are thus expressed in units of  $\text{km}^{-1}$ . On the contrary, yellow eel mortalities are expressed in  $\text{year}^{-1}$  since they are applied to a standing stock over the duration of the fishing season.

The amount of silver eels within a super-eel  $i$  when passing the reach  $j$  decreases by a random number  $N_{dead,i}$  drawn at random from a multinomial distribution with parameters for the number of eels in a super-eel  $i$  and probability  $1 - e^{-F_{silver,j}\lambda_{reach,j}}$  where  $\lambda_{reach,j}$  is the length of reach  $j$ .  $N_{dead,i}$  is also the number of silver eel caught by the fisherman who fish in reach  $j$ .

### **Impact of obstacles**

For each reach  $j$  with a downstream obstacle  $k$  that the silver-eel passes, the amount of eels within a super-eel  $i$  is reduced by a number drawn at random from a multinomial distribution with parameters for the number of eels in the super-eel  $N_i$  and probability  $m_{down,k}$ . The probability of downstream passage is not taken into account in this process ( $P_{down,k}$  is forced to 1) in order to force all the silver eels to leave the catchment the season they become silver, i.e. none regress to the yellow stage after first transforming to the silver stage.

The number of eel passing the obstacle  $N_i (1 - m_{down,k})$  is also recorded in the record list of the obstacles.

### **Behaviour of Scientists**

The simulation of the scientists was based on the virtual ecologist concept (Berger *et al.*, 1999). They are used as the interface between the CREPE virtual world and the stock assessment models. Three scientists were created: the electro-fishing scientist, the fishery scientist and the obstacle scientist

#### **Electro-fishing scientist**

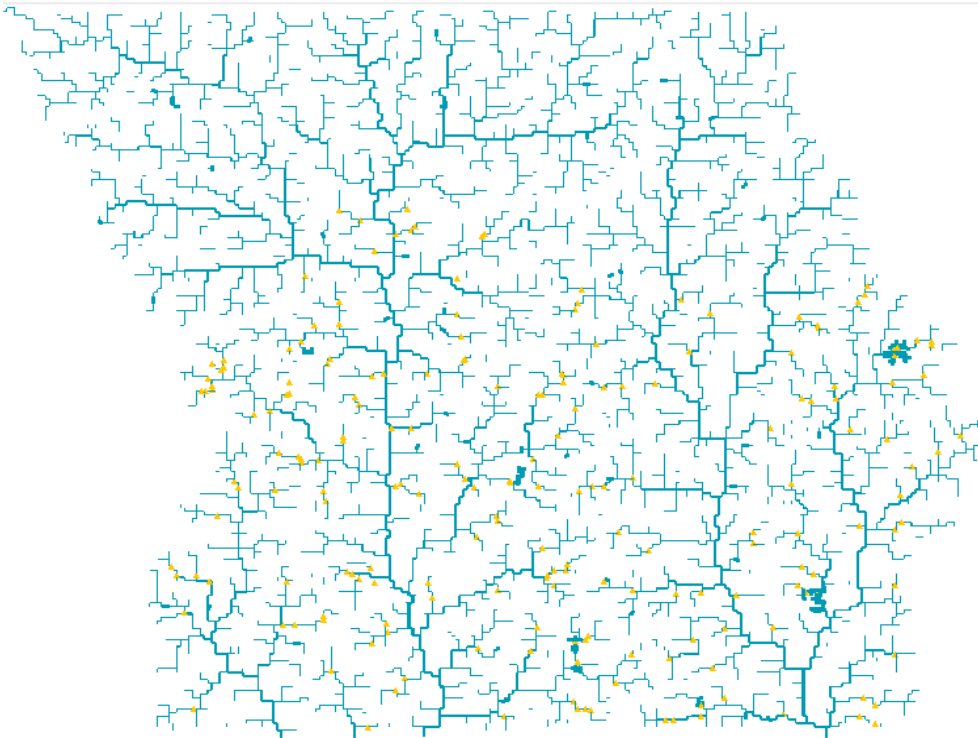
The aim of the electro-fishing scientist is to perform electro-fishing operations in a selection of reaches and to analyse the length distributions of yellow eels in the survey catches and populations surveyed.

We fixed the density of electro-fishing stations to 0.005 stations per km<sup>2</sup> as this is similar to the value observed in the French electro-fishing survey. In order to distribute the electro-fishing stations in the parts of the river basin where electro-fishing would be practical and where eels were likely to be found, a total of 200 stations were randomly distributed in reaches where the depth is lower than 2 m, the distance to sea is less than 150 km and the distance to source is greater than 5 km (B14). The length of each fishing station was fixed at 100 m, and the width was either the width of reach for those less than 10 m wide, or to 10 m for wider larger reaches. The fishing operations took place during autumn.

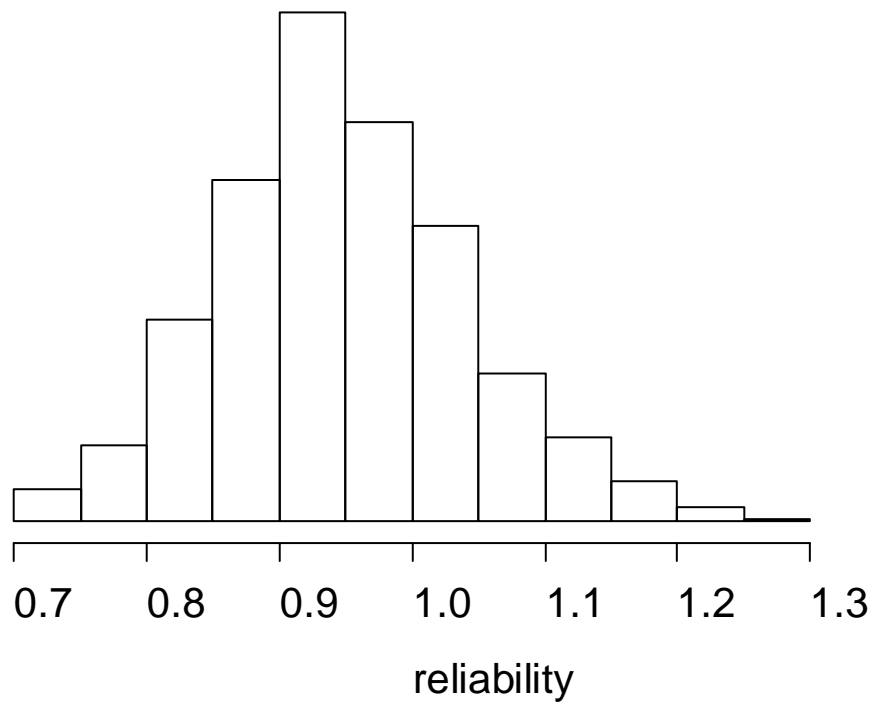
We defined the reliability (combination of accuracy and precision of sampling and estimation methods) of an electro-fishing estimate of local population size as the ratio between the estimate based on the electro-fishing operation and the actual number of fish present in the fishing station.

This reliability in the model was drawn from a log-normal distribution (B15) where the mean  $\mu_e$

and standard deviation  $\sigma_e$  of the normal distribution were -0.05 and 0.1, respectively.



**Figure B14.** Location of electro-fishing stations (orange triangle) in the river networks



**Figure B15.** The normal distribution of the reliability of the local population estimate used to simulate electro-fishing operations

The estimate derived from the electro-fishing catch of the number of fish present in a station is then the amount of eel in a reach times the product of reliability and the ratio between the fishing station surface and the reach surface.

No selectivity according to fish length was taken into account in this electro-fishing operation simulation.

With the selected parameters, the proportion of electro-fishing operations with presence of eel was around 15% during periods of high abundance of eel (first years of simulation) and around 5% during periods of eel scarcity. These values are less than the 30% observed in the French survey during the last 20 years.

### Fishery scientist

The fishery scientist gathers information from fishery records produced during the “glass eel arrival”, “standing stock mortality” and “catadromous migration” processes. The scientist calculates the total catch and effort for each fisherman on an annual basis. He also collects biological information (length, weight, gender, stage) of fish for a sub-sample of the catches

### Obstacle scientist

The obstacle scientist follows the passage of eels over the dams by analysing the records produced during the simulation of the impacts of each obstacle. He is not used for POSE simulations.

## CREPE model run

The flow chart in Figure B16 illustrates the scheduling of the processes in CREPE simulation at each time step. Figure B17 shows more precisely the succession of biological processes for a super-eel during the four seasons of a year.

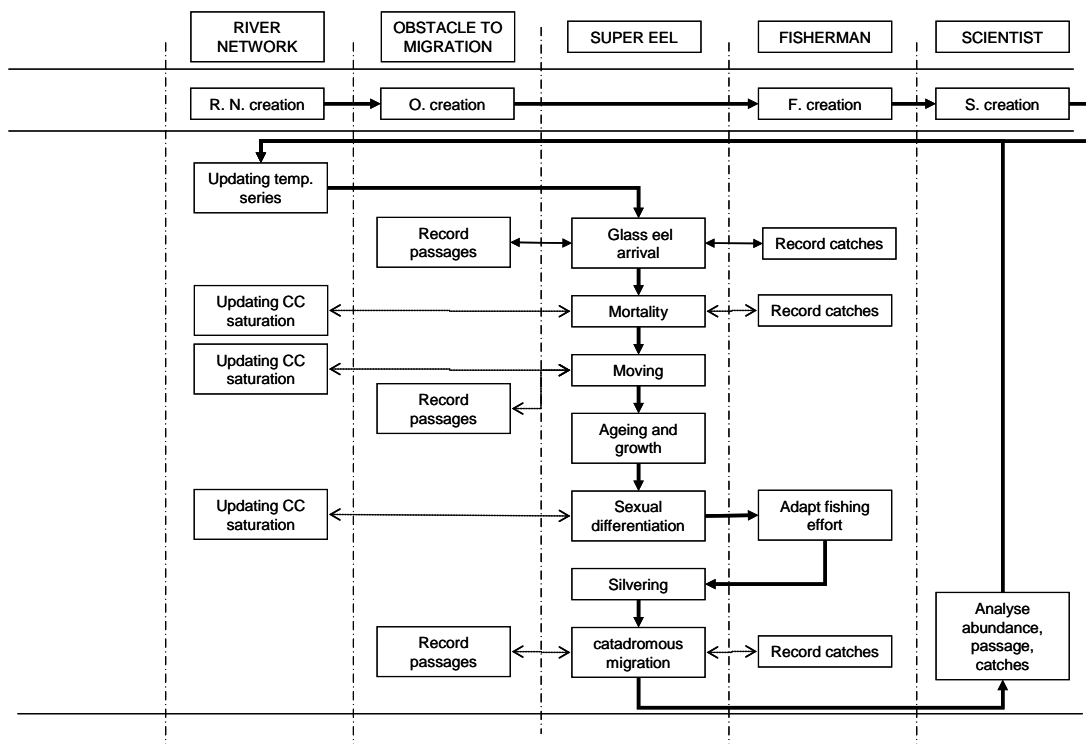
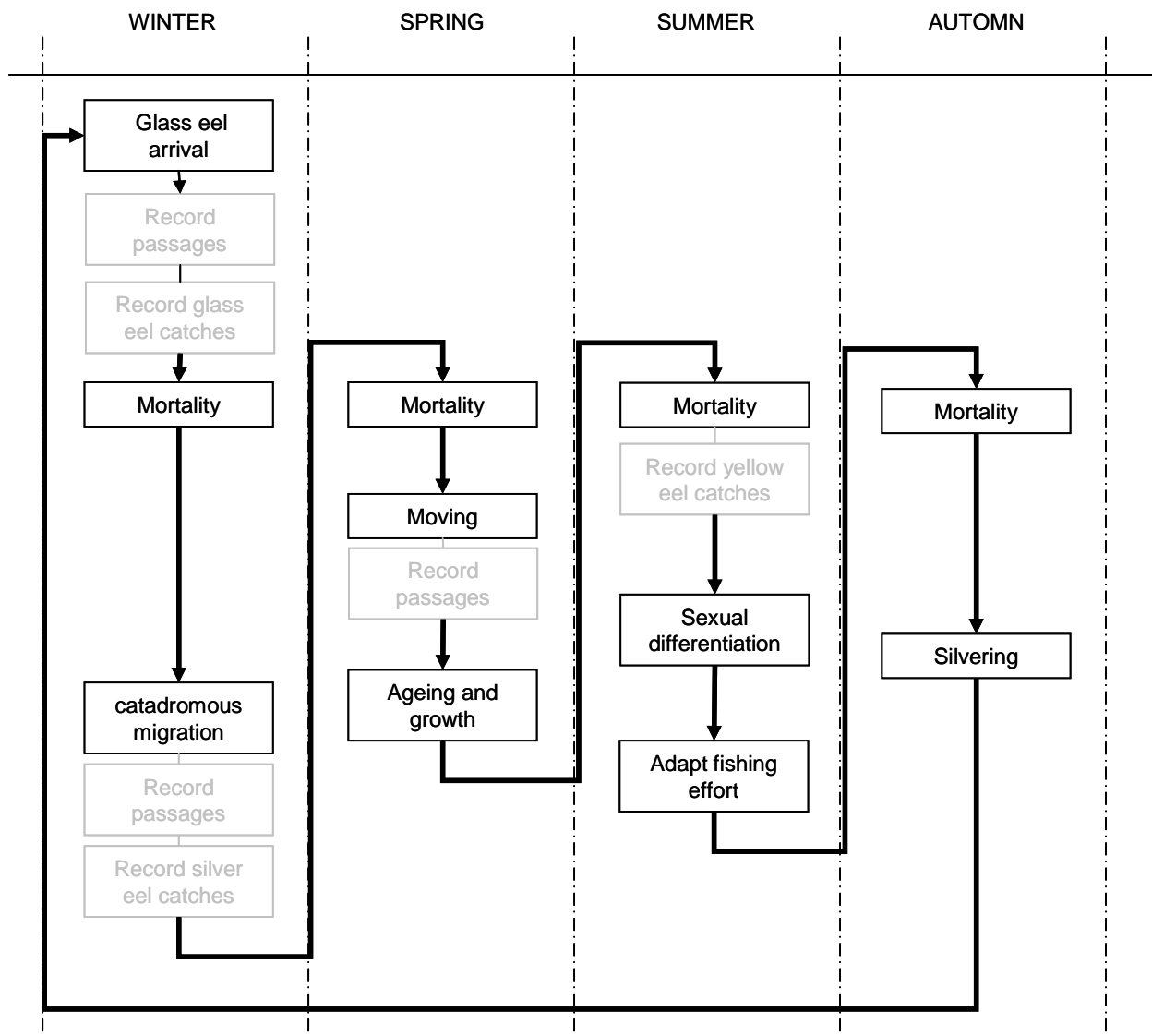


Figure B16. Flow chart of processes in CREPE simulation





**Figure B17.** Flow chart for super-eel processes during a year of simulation (4 time steps)

### Acknowledgments

The development of CREPE model was supported by the French National Agency for Water and Aquatic Environments (ONEMA).

## **Annex C. Structure of the DataBase for Eels (DBEEL)**

This is supplied as a separate pdf document.

## **Annex D. Description of the development of an eel production model to apply in cases where no eel data are available**

This annex is supplied separately as a .pdf document.

## Annex E. Minutes of project meetings

### E1. Minutes of DG MARE meeting 20-11-09

*Present:*

Antonio Cervantes (European Commission) – AC

Christos Theophilou (European Commission) - CT

Gilles Doignon (European Commission) - GD

Alan Walker (Cefas) – AW

Michael Clarke (Cefas) - MC

1 – Alan Walker (Cefas) gave a brief presentation of the project and then answered questions from the EC representatives:

CT – Have management plans of other countries been seen?

AW – Confirmed that Willem Dekker has obtained most draft plans, though some are written in the native language of that country.

CT – Is Portugal one of the countries involved in supplying data?

AW – We have access to data from other countries, but will mainly be working with the data from the countries mentioned in the presentation.

AW – Informed the panel that a project kick off meeting has been planned for 9<sup>th</sup> & 10<sup>th</sup> December 2009, to be held at Stansted.

GD – Have other Eel types such as Glass and Yellow been considered and not just Silver Eel?

AW – Yes, in that yellow and/or glass eel data may be required to inform the models.

GD – Will there be dealing with ICES via Willem Dekker?

AW – Russell Poole is the chair of the EIFAC/ICES WGEEL so the main contact with ICES. Russell is one of the project partners.

GD – Will the toolbox be translated into French?

AW – We have not allowed for translations within our budget and this was not a requirement of the project. In order to achieve this additional funds would be required unless DG MARE were able to resource this.

AC – There is no requirement for this translation.

GD – There are French Fishermen who work with IFREMER, involved with the Indicang project that have data since the 1980's, they could prove useful.

AW – Agreed to discuss with our French partners to pursue this as a potential data source.

AW – Gave details on funding opportunities for the dissemination workshop

AC – There is a planning group within ICES (PGCCDBS) who organise events, this could be an ideal platform for the dissemination workshop,

AW - Mike Armstrong from Cefas is our representative on PGCCDBS, so we will discuss an approach with him.

#### *Main points addressed in the evaluation report*

AC – Although this was the only tender submitted, it received a score of 75% which is a good rating. The tender lost points by not fully addressing the issue of quality control. It would be worthwhile disseminating this information to your peers at Cefas, particularly as Cefas is one of DG MARE's main contractors.

#### *Schedule and contents of deliverables*

It was agreed that the interim report would be submitted on 30<sup>th</sup> April 2010 and the draft final report submitted on 31<sup>st</sup> August 2011.

AC – What is the intended content of the reports, how will the issues be addressed. We would like the reports by task, indicating not only activity but also how each task is progressing.

AW – The interim report will explain models and selection data issues. The next report will focus on model testing, extrapolation of data then best practices. The interim report will form part of the final document.

GD – The interim report needs to include a justification of the basins selected.

AC – The Commission want to be informed which basins have been selected. This can be communicated informally in an email to Antonio Cervantes. Minutes from all meetings need to be included in the reports.

CT – Are there conflicts of interest in models used?

AW – Partners have agreed to provide the models and datasets. The toolbox will be offered to member states, it's then their decision whether they use it or not.

CT – Christos asked to be informed if any issues arise whereby the project might recommend other models as more appropriate than those used in a particular country.

### *Financial & Administrative Issues*

MC – We have no contractual or financial issues, we have received the pre-financing and this is currently being distributed to the partners.

AC – If for what any reason there are partner changes, these need to be communicated to the Commission.

### *Other Issues (e.g. state of play of EMPs)*

GD – Reported on the status of the evaluations of EMPs, noting that outstanding issues with those of France, Spain, Portugal and the UK meant that were not due to be submitted for approval at the time of the meeting.

Meeting was closed by Antonio.

## **E2. Minutes of First Team Meeting**

9<sup>th</sup> to 10<sup>th</sup> December 2009, Radisson Hotel, Stansted, UK

### **1. Introduction from Alan Walker**

AW thanked everyone for their efforts in developing a winning proposal. Quick introductions were made around the table. The agenda was reviewed and agreed.

### **2. Project management**

(WALKER & CLARKE: rapporteur APOSTOLAKI)

Kick-off meeting with DG MARE in Brussels, 20<sup>th</sup> November 2009.

AW provided a summary of the key discussion points, noting that the proposal was marked highly, but could have provided better description of the methods to applied to address quality control.

The deadlines were agreed as 30<sup>th</sup> April 2010 for the interim report, 31<sup>st</sup> August 2011 for the draft final report, and 31<sup>st</sup> October 2011 for the final report.

The interim report will describe the models and river basins and explain their choice, and will include Minutes of the Brussels and Stansted meetings.

AW to informally report to DG MARE the final selection of River Basins in April 2010, and if and when necessary, make DG MARE aware if final toolbox might suggest application of models other than those used by Member States.

All reports to be provided in English, and no translations are required within the project.

Roles and responsibilities within the project: All WP leaders and others confirmed they are happy with their roles.

Risks and issues (availability of data and models, availability of expertise and their time, costs against budget)

Participants confirmed that they still have access to the necessary datasets; the payment schedule is satisfactory.

WD is moving to Sweden early in 2010 but will still be employed by IMARES for the purposes of this project. WD and PL would review the schedule for provision of simulated datasets in light of this move, but no problems were anticipated.

RP reported the loss of his statistician and imposition of recruitment freeze at MI caused some problems for WP 5, but was exploring possibilities for subcontracting, subject to no nett cost impact. PA asked that other partners explore possibilities for them to provide statistical support.

MC introduced himself to the group and summarised the project administration and payments processes. He stressed that participants should keep all the receipts from their travel, and that proof of time that the participants have spent working in the project will be required.

Actions: Michael to confirm rules and restrictions related to subcontracting, and requirements for retention of receipts.

### **3. Project plan – overview of WPs from leaders**

AW reminded everyone of the aim, deliverables and approach of the project:

Aim: to develop and analyse methods of estimating silver eel escapement rates from various inland and/or coastal environments

Deliverable: a toolbox for the scientific assessment of eel stocks against the EU Regulation Target, to establish best practice in assessing eel stocks status, their management and future monitoring

Approach: test applicability and accuracy of models against real and simulated data-rich examples; establish minimum and priority data requirements for model application using real and simulated data-poor situations; develop framework for model transfer to various data-poor situations, illustrated using case studies from the three regions

#### ***WP1- Select & classify basins***

(WALKER, rapporteur: APOSTOLAKI)

AW presented the list of deliverables for this project and provided a description of each of them.

Our proposed approach was revisited to ensure that all partners were clear about the work needed and to reiterate the reasons and situations that led to this approach

The question about River Basin vs River Basin District (RBD) was raised, noting the difference in terms of practicalities of scale for model application vs variety and comparability of scenarios, could be significant and that we should make it clear whether we refer to RB or RBD in our discussions. It was noted also that some eel management plans (EMPs) used Eel Management Units (EMUs) that were different from the RBDs. Therefore, we will refer to RBs and EMUs (which include RBDs).

There was then some discussion about whether we should work on individual river basins (i.e. 2 data rich, 2 data poor and 2 no data basins) or choose 6 EMUs within which there are examples of each. This decision was deferred until after everyone presented their candidate case studies.

Trans-boundary EMUs were considered. Although they are a real management-related situation, their direct assessment is beyond the scope of this project, which will not specifically address issues related to collaboration between countries in developing their EMPs.



### *WP2- Describe assessment methods*

(APOSTOLAKI, rapporteur: WALKER)

After considering the format for reporting model descriptions, we agreed to provide a brief text description, along with a tabular matrix comparing the models against [processes covered and data requirements]. Published model descriptions will be cited for further information. We will also report on other approaches (other than simulation modelling) that could be used to estimate silver eel escapement (e.g. direct counting, tag-recapture, traps, etc.)

To avoid issues of ownership and Intellectual Property rights (IP), the toolbox will provide model descriptions and suitable application scenarios, and contact details for model 'owners' and but not the models themselves (i.e. source code, executables, packages, etc). It will also provide information about the expertise required to use each model and whether people can have access to the source code or just to an executable.

Model descriptions will note the minimum input data requirements, and list all the information that the model can use (informing WP3). This description will be presented as a matrix table. A first version of that table was developed during the meeting (PDA) and was populated using input from the model developers.

A brief presentation was given of the manner in which models simulated processes, data requirements and outputs.

List questions that the EMP needs to address and the questions they will need to provide and identify what of these answers each model could provide or can contribute to the contraction of a response to those questions

Modellers will provide model descriptions, including data requirements and outputs, and summarise this information in a matrix

Actions: Alan to further modify model matrix from Peer, and distribute this and dataset matrix to 'owners' of models and datasets.

- a table that describes the processes that the models simulate (modellers to complete)
- a table that shows which information is used as input data and identify minimum data requirements (modellers to complete)
- a table that shows the data available, and formats, from each case study River Basin

### *WP3- Provide test data*

(BEAULATON, Rapporteur: BEVACQUA)

LB presented three options for the data exchange mechanism (developed and hosted by ONEMA), with increasing levels of complexity:

1. Simple exchange via "ftp" site of data between Data Providers (DP) and Modellers (M) in their native formats;

2. Provide a common format for data, and use “ftp” to share data;
3. An integrated framework where DP uploads all the data they have, and M can download the data they require based on search tools such as “SQL Query” or “ETS”.

The group discussed these options, noting that SLIME used option 1 but the modellers and data providers devoted a lot of pre-testing time to exploring and analysing the data to provide formats suitable for the models.

The data exchange should include geographical data, and be designed to meet needs of present assessments rather than trying to make it ‘future-proof’. The Data Collection Framework provided a common format for data exchange, but not all Member States are collecting the same sorts of eel data or to a single standard.

The SWOT tests of the models will include their data requirements, assessing whether these requirements are clear, and the amount of time and analysis required to provide the data in the appropriate formats.

It is paramount that the data and format requirements of each model are clear from the start. Data requirements should be classed according to those that are essential for model application (“must haves”), those necessary to significantly improve the realism of the model outputs (“ideal”), and those not required. This information exchange will be achieved through the model and data matrices.

We agreed on option 3.

We then discussed the provision of the simulated dataset, which is required to simulate changes in management processes and data availability, and will be used to set a benchmark for model testing, both within POSE and afterwards. The simulations will be created using an Individual-based Model (IBM), which will be based on existing data limits, our current ecological knowledge of eel population dynamics, and of management scenarios and anthropogenic impacts.

Anthropogenic impacts were considered as mortality effects, and organised as oceanic or continental, and direct vs indirect. Direct impacts were such as fisheries, turbines, pollution, lack of water or oxygen. Indirect impacts were such as pathogens, habitat loss or disconnect (resulting in density-dependent mortalities).

Model testing with the IBM data will be ‘blind’ in the first instance, but thereafter develop as an iterative process between the modellers and the IBM data-providers.

Action Laurent to develop Option 3 as the data exchange mechanism. For this, he needs to understand the data and formatting requirements of the models (to be provided by the modellers), and the format of data available from case studies (to be provided by data owners)

#### *WP4- Model testing*

(DEKKER, Rapporteur: OEERST/FLADUNG)

The objective of this WP is to test the applicability, accuracy and precision of models to real, and where necessary simulated, data-rich situations from a variety of representative environments (addresses ToR 7), and determine which temporal and spatial changes in status can be detected, what data and parameters are most influential in determining model accuracy and precision, whether models will detect effects of management measures, and priority and minimum data requirements (supports ToR 5, 6, 7 & 8).

During the meeting, a flow chart was developed/presented describing the flow of information from the data gathered in the field data, via model selection and tuning, to model testing and simulation of various management scenarios. Cross-links to other work-packages and external projects/workshops were identified.

Subsequently, a range of options for testing model performance was formulated, including:

- selection and parameter fitting based on a full data set
- comparison to a model fit based on a thinned data set
- comparison to a model fit based on the full data set with added stochastic noise
- comparison to a model fit based on artificially constructed (simulated) data sets, with varying degrees of stochastic variation in process parameters and/or “measured” variables
- application of a model (with/out fixed parameter values) to case studies other than the one for which they were developed
- application of a model (with/out fixed parameter values) to other time periods (cross-link to ICES workshop SGIPEE, post-evaluation)

Alternatively, the sensitivity of a model to changes in input data and/or assumed parameter values can be analysed directly in a sensitivity analysis. However, it was agreed that this type of testing must be realized within WP3. The aim of WP4 is to assess the robustness of the models with respect to the availability of data (covering data rich to data poor), in assessing the fundamental stock status indicators (biomass and mortality).

The descriptions of the models for estimating the escapement of silver eel clearly shows that very different levels of spatial and temporal distributions of the input data are required. Therefore, assessment is necessary on which model is the most appropriate for different data situations or types of input data. An aggregate of the input data in space and time in combination with a less complex model can be useful if the input data of the more complex model are uncertain.

Series of reduced data will be produced based on the available data from the different EMUs as well as artificial data will be simulated to evaluate whether the models describe the changed reality and whether the models detect errors in the input data. The models will be ranked according to these evaluations, but criteria will be developed during the project.

Actions: WD and PL to develop the list of SWOT criteria, to distribute this to the group, and to develop the IBM

*WP5- Extrapolate to data-poor*  
(POOLE, Rapporteur: DE EYTO)

RP summarised the work required for this WP.

A transfer or extrapolation from data-rich to data poor should allow the user to calculate biological reference points for conditions in the absence of anthropogenic impacts. The “extrapolation” could be within a catchment (e.g. across a number of survey sites), as well as between basins, RBDs or EMUs. The extrapolation may also need to be possible across the entire eel range, from Norway/Baltic to the Mediterranean/N. Africa.

RP proposed a Bayesian Hierarchical Analysis of eel production in the data-rich catchments, from which to enable estimates of silver eel escapement in catchments with limited or no eel data. This approach has been used, coupled with latitude and wetted area, to derive conservation limits for Atlantic salmon populations in data-poor rivers.

The four tasks of the WP would: review data available to support an extrapolation framework; identify probability distributions of silver eel productivities against proxies and covariates; develop the Bayesian framework to estimate local escapement from extrapolated productivity; and, apply the framework to region-specific case studies and develop verification standards to ensure highest level of consistency.

The response variables will be silver eel production and yellow eel standing stock (both as kg/ha), and anthropogenic mortality rates, and the explanatory variables will include factors associated with the potential productivity of a study area (e.g. distance from sea, river gradient, presence of instream structures or barriers, alkalinity, conductivity); wetted area; eel population descriptors (e.g. age, growth, sex ratios, observed numbers or biomass); inputs (recruitment and stocking); and anthropogenic impacts.

The Hierarchical approach for eels will need to include estimates of glass eel (and other stages) fishing mortality, and other sources of anthropogenic mortality such as turbines, and take into account density-dependent effects on life processes, in circumstances where they are expected to occur.

LB noted that some aspects of the French EDA model would be particularly well suited to a Bayesian analysis. The EDA model is based on yellow eel electrofishing data extrapolated for the whole of France, and then converted to silver eel escapement using a value of 5%.

The approach will be developed during the first 6 months of 2010 through discussions and meetings with experts in order to fully map out the method and body of work, which will be conducted during the 2<sup>nd</sup> half of 2010.

Action RP to develop approach, providing regular updates to team.

#### *WP6- Develop best practice*

(WALKER, rapporteur: APOSTOLAKI)

AW reminded the team that the toolbox will take the form of a Guide to Best Practice, including an overview of the assessment and management scenarios; a SWOT of models and model-free approaches; descriptions of the models and their application to data-rich, -poor and no-data scenarios; and the contact details for those who are responsible for the dissemination of the various models.

Participation in, and funding for, the User-Trial Workshop (WS) were discussed.

Both scientists and managers can benefit from the WS but the two groups will have different expectations. For example, we anticipated that managers would attend the first part of the meeting to gain an overview of the purpose and capabilities of the toolbox, while scientists will also attend the second session in order to familiarise themselves with the specifics of the toolbox and even try to apply it to their data.

Finding funding for this workshop still remains an issue since the project can only pay for representatives of the project partners to attend. DG MARE suggested that, given the links between the LOT Programme and the inclusion of eel in DCF, we submit a proposal through the PGCCDBS for the funding of the workshop. As an alternative, the group suggested setting up an STECF meeting in ISPRA

Action Alan to explore submitting a WS proposal to PGCCDBS in time for their March 2010 meeting, and to explore alternatives.

#### ***WP7- Project management and reporting***

(WALKER, rapporteur: APOSTOLAKI)

Cefas will conduct regular reviews of project progress and delivery; organise meetings and the workshop; and, compile and submit all scientific reports and financial reports.

## **4. Review EMPs to define data rich and data poor criteria**

(WALKER)

As most EMPs have been written in their native languages, it was not possible to conduct a complete review prior to the meeting. Therefore, we concentrated on reviewing the information available from basins and EMUs of the project partners.

## **5. Summary presentations of candidate basins**

(DPs)

The river basins and EMUs proposed for case studies were briefly described by each of the data providers. Key points are summarised here, with further descriptions provided in the interim and final reports.

**IRELAND (RP):** the Irish Western River Basin District (WRBD) covers the area from Galway to Sligo on the Atlantic west coast of Ireland. There are 69 RBs producing eel, with 2 data-rich RBs, the Burrishoole and the Corrib, with the remainder either data-poor or no-data basins. Within the RBD there are 14,200 km of river, 5,170 ha of lakes and 47 oligohaline lagoons. There were yellow and silver eel fisheries but these were closed in 2009 as part of the EMP. There are hydropower schemes. There is no glass eel recruitment index, but there are historical fishery- and survey-based assessments of yellow and silver eel production.

**FRANCE (LB):** The Brittany EMU has about 275 river basins, with the Vilaine (10,500 km<sup>2</sup>) accounting for about a third of the drainage. Wetted areas of rivers and lakes are similar (~80 km<sup>2</sup> each), and about 215 km<sup>2</sup> of transitional waters. The dominant land-use is livestock agriculture. There are few glass eel fisheries, plus net/trap and rod-and-line fisheries for yellow eel. Obstacles to eel migration have been mapped, including turbines, abstraction points and weirs. Restocking of eel occurs in upper reaches of some basins. Eel data are available from multi-species and eel-specific surveys. The Rhone EMU includes rivers and extensive lagoon habitats. Presence and absence of eel has been mapped in relation to potential obstacles.

**GERMANY (RO):** The Elbe RBD is shared between the Czech Republic and Germany (with small parts in Poland and Austria) – only German part is considered within POSE. There are 400+ commercial fishing companies and about 350,000 recreational fishers. Eel have been stocked since 1995, though glass eel stocking ceased in 2006. Commercial catches of eel have declined by about 40% since 1985 but recreational catches remain at recent historical levels since 1998 after a minimum between 1992 and 1997. Eel data are available for recruitment, stocking, mortality by fishing, hydropower and piscivorous birds, and silver eel escapement.

**SPAIN (ED):** There are 11 river basins in the Basque Country Inner RBD. Typically, the rivers in these basins are very short and steep. Human population densities are high throughout the area and therefore the rivers suffer from high morphological pressure, with highly modified water masses including many dams, and destroyed ecosystems. Eel are found in all the rivers except upper areas where access is blocked by dams, but there are some areas where the habitat and water status is still poor and where pollution is a considerable problem. Eel abundance has generally increased in the Gipuzkoa region, but maintained or decreased in the Bizkaia region. There is a traditional glass eel fishery, regulated since 2003, with detailed catch data (daily catch and effort) from '03 to date. There was a very small sport fishery for yellow and silver eel but this has been closed since 2008. Data include multi-species electro fishing survey data from 1992, eel-specific survey and recruitment data for the Oria since 2004, an inventory of dams and hydroelectric power stations, and other geographic data for the WFD. The Basque eel management plan includes very detailed survey of the Oria and the Barbadun rivers.

**UK (AW):** Five RBDs of England and Wales discharge into the North Sea, though only 1 will be considered within the early stages of POSE. The eel-producing areas are characterised as primarily being rivers. Substantial transitional areas exist but there is very little information on eel production from this environment. There is no glass eel fishing, but local concentrations of yellow and silver eel commercial fishing. Turbines and other obstacles to movement of eel have been mapped but not assessed. Eel-specific survey data are available from one river, and from 100's of multi-species survey sites, per RBD. More eel-specific surveys are being conducted for the EMPs. [subsequent to

the meeting, Miran Aprahamian of EA proposed the Anglian RBD for POSE. It includes the Suffolk Stour and Nene rivers as both have relatively good yellow eel data, some silver eel counts, fishery and/or turbine impacts and stocking].

#### *Other potential case studies*

The group noted that the above list of case studies met the regional requirements of the project specification, i.e. 6 case studies distributed throughout the Baltic/North Sea, Atlantic and Mediterranean regions and providing data-rich, data-poor and no-data situations. Given the diversity of eel-producing habitats, anthropogenic impacts and potential assessment situations across even the European range of eel, however, the group felt that two additional case studies should be sought, from the eastern Mediterranean and from the Baltic. Therefore, we approached colleagues in Italy and Sweden, who have since both agreed to make datasets from their countries available for free to the project, subject to reasonable and acceptable requests for acknowledgement of these contributions.

## 5. Presentation of models

The main eel assessment models were briefly described by each of the modellers or their representatives. Key points are summarised here, with more detailed descriptions provided in the interim and final reports.

**Scenario-based Model of Eel Populations (SMEP II) (PA):** A length-based model that describes the dynamics of a population of eels throughout a river basin, and includes sex-, life stage-, and area-specific components, and accounts for density-dependent effects and habitat structure and quality. The model consists of 3 main components: a) a model that simulates both the biological characteristics (growth, natural mortality, sexual differentiation, silvering and movements) of the eel population and a number of potential anthropogenic influences on that population (environmental and habitat quality, fishing practices, barriers to movement, and stocking); b) a GIS tool that helps the user determine the spatial structure that they want to use for their calculations and prepare the input files for the population dynamics model to run; and c) a statistical model that is used to estimate some of the parameters of the population dynamics model. Model outputs are provided both as numbers and biomass of eel, per sex and life stage, river reach and year; and length frequency distributions.

**Irish Model to Estimate Silver eel Escapement (IMESE) (RP):** Catch-based estimates of historic/pristine escapement were developed for 4 basins where present-day silver eel escapement, fishing exploitation rates and impacts of hydropower were known, and for 1 basin with similar data from scientific surveys. Productivity estimates were corrected for unreported and illegal fishing. The four fishery catch-based, and one survey-based production estimates were plotted against the proportion of non-calcareous geology within the basin to derive a relationship between area-specific eel production (kg/ha) and basin geology. Potential silver eel productivity was regarded as a product of recruitment, natural mortality (14% per annum), and average age and weight of silver eels. Another model was developed from eel productivity (growth rates) and the geological characteristics of the catchment (proportion of calcareous geology) for 17 basins.

It was noted that the future application of this model (or updating of results) in Ireland will require updates to eel population data which have historically been collected from fisheries, but are at risk because of the closure of the Irish fisheries. In such circumstances, other methods need to be employed in order to populate the models with meaningful data, e.g. mark recapture data, electrofishing surveys, etc.

**German Eel Model (GEM) (RO):** An age-based model developed to describe the dynamics of the River Elbe eel population with data from 1985 to 2008, and especially to estimate silver eel escapement between 2005 and 2007. The river is treated as a single unit, i.e. not accounting for spatial aspects like habitat quality, and a 94% female sex ratio was assumed throughout. The model is based on the VPA concept, but projecting forwards. The starting population was the estimated number of eels per cohort in 1985. The population in 1986 was then estimated, accounting for natural and anthropogenic losses per cohort, and inputs of recruitment and stocking. Input data are provided as numbers per cohort, with various counts or length distributions converted to age profiles based on survey data. A weight-length relationship and growth rate are used to estimate the mean weight per cohort and to transform length-based estimates into age-based estimates. Model outputs are population size, catch by fishermen, catch by anglers, catch by cormorants, mortality by other natural reasons, and silver eel escapement, all expressed as numbers per cohort.

**Eel Density Analysis (EDA) (LB):** this is a framework of eel density analyses rather than a fixed model. It relates eel densities to environmental variables, including anthropogenic impacts, and is extrapolated from survey sites to the river basin. The predicted yellow eel stock is then converted to a silver eel escapement, using a conversion rate developed from French studies. It has been applied to the Brittany EMU, the Loire+Brittany EMU, and most recently to the whole of France.

**Demographic model of the Camargue (DEMCAM) (DB):** This is a stage-, age-, and length-structured model, similar to SMEP II but simpler since it does not integrate detailed spatial heterogeneity beyond river, lagoon and lake, and does not consider the movement of eel. The required parameters are: Annual recruitment (time series or index); Sex ratio (at silver stage or at 30 cm); Density dependant juvenile mortality (back calculated from historical maximum); Sex specific body growth (otolith, age at silvering); Sexual maturation (silver size); adult mortality (literature, or know); Fishing mortality (know, estimated). The output of the model is number of eels in a given time at a given age, size, sex and maturation stage. Based on this information, the user can estimate the number of migrating silver eels for any given time.

**Other models (RCM, GLOBANG, LVPA, SWAM, SED, GEMAC, etc):** These models were briefly considered at the meeting, but it was noted that none are directly relevant to POSE since they are no longer supported (GlobAng, LVPA, SWAM), are global (SED) or life-stage-specific (GEMAC), or have been rejected by ICES during the EMP evaluation process (RCM).

## 6. Select river basins – IV: agree selection

(ALL, rap WALKER)

Main concern was not to over-reach within the project, especially where we work with the EMU level rather than focussing on specific River Basins, as detailed in the original work programme



specification. Group felt that we should select the 6 (8) EMUs at this stage, and then identify the final data-rich, data-poor and no-data study areas once we had fully considered the data requirements of the various models and the data availability of the potential case studies.

## **7. Immediate tasks**

(ALL, rap WALKER)

information required to describe models and their application – matrices to be developed, distributed and completed.

SWOT criteria for initial model testing – will be developed upon review of the data requirements and data availability.

WP schedules – the preliminary schedule set out in the proposal Gantt Chart was approved, but would be revisited throughout the project.

Further meetings – a mid-term meeting is planned within the project. However, there are several opportunities during the timeframe when most partners will come together – SGIPEE in May 2010 and WGEEL in September 2010. We will use these opportunities to hold informal meetings to discuss progress, developments and forthcoming tasks.

Integration of POSE with WGEEL, Workshops/Study Groups, etc – approved in principle, to be developed by project leaders and group Chairs.

## **8. List Actions, responsibilities and due dates**

AW to explore use of Google Group or other means to share communications and data within the group: Google might impose file size limits and not support all necessary file formats. Google Groups impose a 10 MB limit for single files, and a 100MB limit for the entire Group, but do allow Excel, Word, .mxd and PowerPoint file formats.

AW to distribute data and model description matrices, for discussion amongst the group, and completion of final versions by the appropriate people. The data and model description matrices should be of similar layout to facilitate analysis of the connections and gaps. The design of the exchange database requires us to identify the standard data categories and formats. Same applies to the development of the IBM.

Cefas to draft the interim report based on descriptions of datasets, models and their data requirements, and to explain how the chosen EMUs and nested river basins provide appropriate representation of the variation in eel dynamics and management across Europe.

## **E3. POSE progress review meeting, Hamburg, 8<sup>th</sup> Sept 2010**

Attendees: Alan Walker; Russell Poole; Elvira De Eyto; Miran Aprahamian; Ciara O’Leary; Paddy Gargan; Willem Dekker; Daniele Bevacqua; Esti Diaz; Peer Doering-Arjes; Rainer Oeberst;

Apologies: Panayiota Apostolaki; Michael Clarke; Laurent Beaulaton; Celine Jouanin; Patrick Lambert;

Note that industrial action disrupted the travel plans of some who had intended to join the meeting.

### **Meeting aims:**

Review progress to date;

Consider future plans, revising as necessary;

Provide opportunity for DPs and Ms to discuss exchange and tests.

### **Agenda**

0930-1000 Review tasks and deadlines

1000-1030 WP leaders report progress and plans. 1. WP1 and 2

1030-1100 break

1100-1230 WP leaders report progress and plans. 2. WP3-6

1230-1330 lunch

1330-1700 breakout session for data providers and modellers to discuss model tests

1700-1730 Review progress and plans, agree “who does what, and by when”

1730 close.

Minutes

### **Review tasks and deadlines**

Alan referred to the email exchange between Christos Theophilou and Russell Poole regarding developments for the 2012 review of EMPs, and specifically the point by Christos that “POSE will be instrumental in aiding Member States to determine potential and actual silver eel escapement”.

Tasks and deadlines were reviewed with reference to the project gantt chart.

The Reporting Structure was outlined – chapter by chapter.

An issue arose over the wording of the heading for Ch 5, noting that POSE will develop a ‘framework for assessing production in data poor catchments’, but not develop a new ‘model’ *per se*. This will be corrected in the final report.

## Interim Report

The POSE Interim Report was summarized. Alan thanked the team for their efforts in drafting the report, and in quickly responding to the comments by the reviewer(s). The reviewer(s) had suggested adding a section “giving as much information as possible on the effects of parasites, .... , which impair the migratory capabilities of eel”, recognizing that the potential and actual escapement of silver eel does not necessarily reflect the reproductive capacity of the stock. However it was agreed that this was outside the specifications of the project.

Action 1 – All - The group was asked to continue to comment on the Interim Report as the main body of work will be used in the final report (ongoing).

## WP3 Data Exchange Presentation: Laurent Beaulaton

In the absence of Laurent or Celine, Alan presented the powerpoint on the WP3 Data Exchange mechanism.

It was noted that the Eel Database would probably be of wider use to the eel science community and therefore its development was mindful of this fact. However, this wider use will only be subject to common agreements regarding data provision and proper acknowledgement of source and contribution. As this data exchange issue extends beyond the POSE project, the ICES WG on Eel (WGEEL) will discuss what will happen to the database after POSE is completed with further agreements over use of data required.

Given the short and tight time schedule of POSE, it is important that the database is first populated with the data that are essential for the application of the models. Additional data can be supplied later if it takes too long to provide and input just now. It was noted that it is very time consuming compiling the environmental data to accompany biological eel data and a lot of data compiled for SLIME were not used in the final model applications. It was agreed that there is a need for clarification over what data are required by the different models within POSE.

Action 2 – modellers - A full description of required fields to be supplied to DPs via Alan in order to cut down time spent organizing and supplying data.

Action 3 – Elvira and Laurent - Elvira will liaise with Laurent to check if similar fields are required for WP3 database and WP5 dataset (asap).

Several questions were posed regarding the Data Exchange Procedure, which have been forwarded to Laurent via these minutes:

Is it possible to supply required fields with null values for the additional fields in the database which can be filled at a later date when time permits? It is agreed that the database should be future proofed and will eventually need additional data.

*Can Laurent explain the hosting issue with the database?* Is an external connection needed for server for outside access? Ultimately, perhaps the ICES Data Centre might host the dataset, as they do similar for marine data. However, this is a question for after POSE.

Laurent’s presentation included a timeline with dates for data providers to submit data to the database, and for the data to then be distributed to the modelers.

Action 4 – Laurent –to answer these questions as appropriate (asap)

Action 5 – Alan and Russell – Various time schedules were presented during the meeting. Alan will combine these and distribute.

Laurent had raised three topics for discussion in his presentation: geographic scale and precision, standard life history equations; and, standard nomenclatures. These were discussed by the meeting as follows:

**Geographic scale and precision:** estimates of eel-producing habitat in a single EMU vary considerably depending on the method used to collect the wetted area data. Even when GIS data were used, the scale at which the maps were constructed had a significant effect on the total wetted area. This, in turn, has an impact on the relationship between productivity rates and total production and escapement. Most of the countries represented at the meeting have GIS river/lake maps at scale 1:50,000 or better. However, we recognized that this was not standard across Europe. The Pan European River Network from CCM is standard and available to all. However, it is based on 1:250,000 scale maps and therefore does not include most 1<sup>st</sup> and 2<sup>nd</sup> order streams. The assessment of wetted area will have impact on the productivity. This will be discussed in the ICES WGEEL 2010 Sub Group – Local Stock Assessment and POSE will consider it again after the WG has met.

Action 6 – Elvira –to confirm whether the WGEEL reached agreement on a standard for GIS maps used in calculating wetted area (asap)

Ultimately, stock-wide assessments will need to quantify production from North Africa, etc. It is anticipated that the POSE models could be applied to these areas, as appropriate. Even though the habitat and eel data may be very limited from these areas, application of POSE would be expected to, at least, highlight where there are gaps in our knowledge. However, this is beyond the remit of the present POSE project.

*Standard life history descriptions:*

Sex Differentiation – we agreed that in the absence of information we would assume that density dependent effects are restricted to within the cohort where differentiation occurs. The topic was reviewed by Davey & Jellyman in 2005 but there have since been at least two papers reporting density/sex ratio functions (Bark et al 2007; Han & Tzeng, ????) and a literature review is needed to provide a standard function.

Growth – we will standardize to a linear growth function, and as a minimum use terminal length-at-age data. Elvira asked whether we should regress length at age against individual variation or using a mean length for each age? Alan will run the options on his data to compare the results of growth described by Av. Length/age or regression. Elvira has done it on Yellow and Silvers from Burrishoole already.

Maturation – previous study suggested a standard mean length of maturation across Europe but it is time for a review. WGEEL 2010 will review this topic.

Natural Mortality – no standardization possible different for each RBD, but Daniele Bevacqua has recently reviewed the topic and circulated review paper on Working group Share site.

Migration rates within continental waters – no standardization possible, given the variability in local gradient, river flow, water types, etc. However, a review is required to establish whether there is information on a standard function describing the tendency to move upstream or downstream in relation to varying densities (cf. Ibbotson et al 2002, Feunteun, 2003).

Action 7 – consider review of the literature since 2005 to provide a standard function for density-sex ratio?

Action 8 – Alan and Elvira – compare growth functions based on individual or mean data at length. asap

Action 9 – Daniele – summarize the findings of the WGEEL review of length at silvering. asap

Action 10 - consider review of the literature to provide a standard function describing the tendency to move in relation to density gradients?

**Nomenclature:** this is a topic for WGEEL as well as POSE, so it was anticipated that it would be considered by WGEEL 2010. For POSE, partners were urged to ask questions in relation to the data and descriptions if they do not understand. A description of the data fields with units, and font requirements will be circulated to group with comments, and should be returned to Alan & Laurent.

Action 11 – Laurent – include units and guidance in the datasheets for data input, and ensure terms are standard throughout the data collection (asap & ongoing).

### **Contribution of Task 3.3 and 4.1 by Lambert & Dekker**

An overview of the artificial river simulation was presented by Willem (and Patrick), noting that further developments will take place in the last quarter of 2010.

It was noted that the river network does not include lakes or lagoons, or transitional and marine waters, though a river branch could be transformed into a lake by increasing the wetted area. Willem and Patrick will consider how to address these comments.

As there are many sets of possible model-test scenarios for each biological parameter, it will not be possible within POSE to test the models against every conceivable scenario. Therefore, a series of reference datasets will be constructed with specific variations/alternative biological parameters such as a trend in recruitment, growth rates (linear vs VB), sex differentiation rates (fixed 50:50 at glass eel stage vs density dependent), natural mortality rates (constant vs decreasing with length, increasing with density), fishery mortality (static vs dynamic control), dam mortality (reducing upstream movement, mortalities), and available eel data (electrofishing sites, C, F, CPUE, counts of eels passing a location).

The criteria for testing the models were presented as accuracy (the difference between the true measure and the model estimate), precision (the measure of uncertainty), and sensitivity (to detect the correct scenario). Additional criteria may consider the 'ease of use', applicability, robustness, quality assurance, and resource requirements.

Willem presented a time line for the delivery of the simulated datasets and the subsequent model testing.

## **WP5 Extrapolation from data rich to data poor systems**

Russell Poole presented overview of work package. The framework for WP5 is a continuation of the IMESE model used in the Irish Management plan. The framework will use catchment environmental data to assess production from data rich catchments, and these relationships can then be applied or extrapolated to data poor catchments. All available growth data for catchments can be used to inform the framework which will be matched with the catchment characteristics.

Francoise Daverat has agreed to allow POSE access to the eel growth dataset she and her colleagues have compiled, which will significantly increase the training dataset for WP5. Discussions are ongoing regarding appropriate approvals and acknowledgement of the data sources.

The Production Estimates table produced by WGEEL 2008 should be updated, and it is anticipated that this will be undertaken by WGEEL 2010. WGEEL members will be asked to provide eel growth data and environmental characteristics data.

It was noted that the framework development will likely depend considerably on the availability of quantifiable recruitment measures, as an input to explain production biomass. As there may be few datasets with quantified recruitment, we may have to use yellow eel data as a proxy for recruitment. Regional levels of recruitment would be a step in the right direction.

Action 12 – Russell and Cedric – review the availability of recruitment measures in the training dataset, and consider method to use yellow eel data as a proxy for recruitment (asap).

Russell presented a schematic of the framework development process - It was not clear how anthropogenic or natural mortality were taken into account before silver eel production.

There is a need for standardization in the methods used to collect eel data, and for methods to calibrate data from one method against others. For example, how many fyke nets are required and how long should they be fished in order to deliver a robust local population estimate? Similarly, how many sites should be electrofished throughout a river network to provide a representative indication of total eel densities? These are issues that concern the wider eel science community and it was anticipated that WGEEL 2010 would revisit them this year.

## **WP6 Dissemination**

Alan presented options for sponsoring the User Trials Workshop. The meeting felt that the workshop should be hosted by the Commission rather than ICES, especially given Christos' comments on the use of POSE by Member States in delivering the 2012 EMP reviews, etc.

Action 13 – Alan – present workshop proposal to Christos, asap.

POSE will not deliver the models freely as part of the final report, since they are owned by individuals and institutions. Rather, POSE will deliver the guidance on which models are most appropriate for particular scenarios, and how to apply them. It will then be up to the Member States and the model owners to agree terms for the application of the model. In some circumstances this will almost certainly require funding, which might preclude some MS from using some models. The

model descriptions in the final report should include a section detailing the resources required for a typical model application, to help MS decide whether to apply such models.

Action 14 – modelers – to document the resource requirements necessary to apply their models (ongoing).

Action 15 – Alan – to make Christos aware of the potential issue of funding affecting the availability of models to some potential users (ongoing).

## **Data Requirements for Models**

With several key people unable to attend the meeting at short notice, the 1:2:1 session between the data providers and modelers was cancelled, in favour of a summary review of the data requirements of each model which would help inform the data providers of the minimum data they had to provide if we were to apply the models to their datasets.

Full details were provided for some of the models during and after the meeting, and are included as an annex to these minutes. The following highlights the key points of discussion around some of the models.

### ***SMEP II***

This will be run at the catchment level not RBD. Therefore there are issues regarding how the model can be used at larger scales, such as RBD/EMU. It is possible to run the model separately for each river basin within an EMU but this would be extremely time consuming. It may be more practical to run the model on one or more index river basins and then extrapolate the results to the remaining RBs.

The data providers saw no major issues in delivering data for SMEP II, accepting that some of the data will have to be drawn from the literature rather than having been collected on the specific candidate river basin.

### ***IMESE***

It is apparent that IMESE is a framework rather than a production model and its development was specific to the data available in Ireland at the time of the EMP development. As such it is not appropriate to apply the IMESE to other datasets. However, the principles of IMESE form the basis of the framework being developed in WP5. Therefore, the MI will focus work on developing WP5 rather than using IMESE in the WP4 model testing.

### ***DEMCAM***

This was originally a single-compartment model but now a catchment can be split into gross areas such as a Minor Stream / Upper area and Main Streams / Lower area and Transitional Waters. However, it was unclear whether eels could be 'moved' between compartments.

The major requirement for Demcam is a cohort sex ratio (% females for 25-35cm). However, a rough estimate that 25% or 50% or 75% of eels in the size class are females will suffice.

A general point is that DemCam will use published values to describe life history processes if stock-specific values are unavailable. This may result in outputs with high uncertainty but it is important to understand and acknowledge this level of uncertainty in all models.

### **GEM**

This model is applied to a single production unit, i.e. there is no requirement for a river network, but at the same time it cannot simulate variability in production around the productive area. As with DemCam, it is possible therefore to apply the model separately to a number of gross compartments, or to 'lump' the productive area together into a single compartment.

The model requires an 18 year time series of training data in order to run effectively. Such a long dataseries may not be available from all of the data providers and it is likely that GEM will only be run on a subset of the candidate datasets.

### **EDA**

Nobody was available to present the minimum data requirements of EDA.

Action 16 – modelers – provide written summaries of the minimum data required (and format) in order to run their models, to allow data providers to clearly see which models they can support with data (asap). UPDATE – all received and provided in Annex here, except DEMCAM.

### **Next Meeting**

Although it was agreed that 1:2:1s between modelers and data providers should be on an ad hoc basis, it was agreed that the partners should meet again during the model testing process to review progress and resolve outstanding issues. January is a good month as it will be after the model testing with real data has been completed, and at the beginning of the model testing with simulated data. A suggestion was made for the next meeting to be held the week of the 17<sup>th</sup> January 2011 in Stansted. However, Onema in Paris was offered as an alternative venue after the meeting.

Action 18 – All – to confirm to Alan whether Paris is a suitable meeting venue in the week beginning 17<sup>th</sup> January (except Daniele who will be in Vancouver).

Action 19 – Alan – to organize January meeting.

Meeting closed.



## E4. Mid-project meeting,

Onema, Paris

18-19<sup>th</sup> January 2011

Aim – review progress and plans, facilitate data exchange and application of models

**Attending:** Alan Walker (Cefas), Russell Poole & Elvira DeEyto (MI), Laurent Beaulaton & Francois Gatel (Onema), Celine Jouanin & Francoise Daverat (Cemagref), Cedric Briand (laVilaine), Peer Doering-Arjes & Erik Fladung (IfB), Rainer Oeberst (OFP), Esti Diaz & Eider Andonegi (AZTI), Daniele Bevacqua (USP) by video-conference.

**Apologies:** Willem Dekker (IMARES), Patrick Lambert (Cemagref), Panayiota Apostolaki (Cefas), Miran Aprahamian (EA)

### *Agenda*

Tues am 0930-1145

Meeting introduction

WP5 (Bayesian framework for no-data scenarios) – progress and what remains to be done, including how we report this WP and demonstrate its application.

WP6 (reporting) – reporting schedule and plans for the workshop

Tues pm 1245-1830

WP3 (Data exchange) – progress and what remains to be done.

WP4 (model testing) – progress with applying models to case study datasets, development of the IBM and virtual datasets

1800 – Skype discussions with Daniele in Vancouver

Wed am and pm 0900-1145; 1245-1700

Discussions between Data Providers and Modellers to facilitate data exchange and model applications

## WP6 Reporting and Dissemination

Draft final report will be submitted on or before the 31<sup>st</sup> August

With summer breaks, we agreed that all documents for the final report would be emailed to Alan by 1<sup>st</sup> August, for collation and redistribution by the 8<sup>th</sup>, and final comments back to Alan by the 24<sup>th</sup>.

### *Workshop*

The original proposal was for a workshop to introduce POSE models (day 1) and then conduct user-trials to gather information about their ease of use with other datasets (day 2). Practically, day 2 now seems difficult to achieve because of the considerable time required to prepare input data for each of the models, time which is not available within the project.

WGEEL 2010 has proposed that the Commission convenes one or more meetings to coordinate and standardise the collection of eel data for national and international assessments. As POSE will provide a suite of tested local assessment methods with associated data requirements, it makes sense to promote the findings of POSE within this wider topic. Therefore, Alan proposed that POSE support the WGEEL 2010 recommendation for a workshop, and actively participate through presentations. We agreed this proposal.

Action Alan to draft a letter for the Commission (Christos Theophilou and Antonio Cervantes), agree it with Russell (as chair of WGEEL) and send it to the Commission as quickly as possible (*update: letter approved and emailed to Comm. Friday 21<sup>st</sup> January – see Annex A*).

## WP 5 Extrapolations

Notes from the presentation by Elvira (see Annex B)

The question of this WP: “In the absence of any eel information for a catchment, what assumptions can we make about the likely eel population, given certain physical and geographic catchment characteristics?”

The collation of data into a suitable format, with checks on data quality, has been a much more complex task than expected. So, work is a little delayed but progressing well. There are only 25 catchments in Europe where we have a good measure of eel production at some point in time. These range from <1 to 49 kg/ha, exclude any data from areas that were stocked, and are modelled separately as pre-and post-1980.

A model of growth rates is available for about 176 catchments (Daverat et al, submitted). The analytical approach of the WP is therefore to link the growth rate model to recruitment (WGEEL time series, and direct measures), natural mortality (Bevacqua et al model) and silvering (WGEEL 2010 review) functions and environmental characteristics of the river basin, in order to estimate potential production from habitats across Europe. This estimate of potential production can then be tempered by human impacts in order to estimate escapement, though this last step is beyond the requirements for POSE.

POSE has increased the range of explanatory variables from those applied in the growth rates model, adding trophic status and geology (both expert judgements), and measures of elevation, slope,

rainfall, maximum Strahler stream order, the fluvial area in the catchment, the length of rivers and the ratio of river to lake wetted area.

There are two elements to the production module – 1. known production rates for 25 river basins; 2. all the other areas where we have eel data but no knowledge on production rate. The approach therefore applies the relationship between habitat, known production rates and modelled growth rates, to estimate the production rates from the other river basins where this measure is not available. The model estimates potential production as 'kg/ha', but then it is up to the user to quantify the productive area in order to estimate the total biomass escapement.

We discussed how recruitment was treated within the model construction and model application. Recruitment has been considered as a trend over time, based on WGEEL time series. However, it was a little uncertain how spatial differences in recruitment strength were treated. For example, two habitats identical in physical characteristics might be found in rivers that flow to the east and west coasts of the UK, and therefore have very different recruitment potentials that impact the productive potential of these habitats.

As the production model has differences in measured recruitment built into the spatial component (i.e. lat/long of each dataset), this spatial difference in recruitment appears to be inherent in the calculations, and therefore the model application. This assumes that the differences in numbers of recruits now are of the same relative proportion as when the data were collected for the construction of the model. It was suggested that in order to test that recruitment number estimates are appropriately modelled, the statisticians might "turn the model around" to estimate recruitment for different lat and long, present this spatial relationship and compare with the few known recruitment data.

In order to better understand the habitats that have been considered in the model development, and those that are outside the scope of the data, Elvira will supply a map showing the locations of all the datasets.

It was not certain what input variables were required to apply the model, so Russell and Elvira would discuss this with the statisticians and report.

Further developments after POSE might consider methods to 'educate' the model for changing recruitment and sex ratios over time, e.g. what happens to potential production estimates as recruitment decreases or increases? A simplistic approach might be to change from using the post-1980 model conditions to those for the pre-1980 conditions, but it is not clear under what increase in recruitment this would become valid.

Cedric suggested using density in the model. Russell and Elvira agreed this had potential to improve the model but would require a lot more work than was possible in the remainder of the project. We noted that this is the first attempt to do this modelling exercise across a huge geographic range, so it is going to raise questions, and we need to appreciate that it will not be perfect.

We discussed the publication of the model, agreeing that this was appropriate for the model description, and that we would have to agree a list of authors, and that discussion would include all the contributors to the growth rate model (Daverat et al). However, we also noted the potential for some political sensitivity if the model was applied to a river basin to provide B0 and Bbest estimates

that differed from national estimates reported to EU Commission. DG MARE had recognised this as an issue at the start of the project, and we have agreed to give them early notice of any potential issues. During the project, however, we will only apply the model to case studies within the partnership, and partners will consider the implications.

We agreed that the model needs to be completed, tested and applied before April, and that regular updates on progress should be made available. We don't expect to apply the model to the IBM virtual data.

#### Actions

- Russell and Elvira to discuss recruitment with the statisticians, and report on how recruitment is treated in model construction and model application, especially in terms of spatial variations, whether the 'reverse model' model approach is an appropriate validation, and what are the input variables.
- The model should be applied to catchments with known production rates, and then to 2 or 3 'no data' catchments to see if the results are similar to expert opinion, and the results from other POSE models.
- Elvira to provide a map showing the locations of all the datasets used to construct the model.
- Discuss publication and agree a list of authors, and the acknowledgement of POSE and DG MARE.

### WP3 Data exchange

Presentation from Laurent

The eel database (DBEel) presently contains eel data from England, Ireland, France and Spain. The structure is being corrected for any bugs during development. A description will be ready soon, and will be included in the report (1<sup>st</sup> August).

Laurent summarised the email-based data exchange process so far.

There have been no requests for Swedish data yet, because none of the models appear to be applicable (this is an issue that Alan will pursue, along with other data scenarios that are not applicable).

No German data have been supplied to the DBEel yet, but modellers confirmed that DemCam will be applied to these data – EDA can also be applied to the Elbe, but using the model calibrated on French eel data. *(Update – Peer and Erik have since explored electrofishing and fyke data from the Elbe to use in the models, but rejected this as a possibility because the eel data are not likely to be representative of the system as a whole, and eel were a bycatch so sampling was not rigorous)*

The English data should be applied to SMEP II, EDA and DemCam, but there have been difficulties with the geolocation of survey sites that must be resolved before data exchange can function fully *(update – Miran and Cedric have arranged access to English survey database to speed up the data input process).*

The Irish data should be applied to all models. Some errors in the weight data have been identified – Cedric has corrected errors in all the datasets – but these will be resolved a.s.a.p., and only affect SMEP II modelling and only in the derivation of a length / weight relationship. A new length at age growth calculation has been provided for Corrib eels. As with other datasets, the Western River Basin lacks measures of recruitment. We discussed whether the Shannon scientific catch data time series could be used as a proxy, and agreed that in the absence of a better understanding, we could assume recruitment size proportional to the wetted area of river basins.

The France (Brittany) data will be applied to EDA. Most of the data are in DBEel already, and the final provisions will be discussed during the meeting.

The France (Rhône) data will be applied to EDA. Most of the data are in DBEel already, and the final provisions will be discussed during the meeting. DemCam may be applied to the Vaccares lagoon if Daniele can get a time series of data from Alain Crivelli.

The Spanish data will be applied to EDA, using French and Spanish calibrations (or only French?), and the Oria river basin (+1 maybe). It was uncertain whether DemCam could be applied, but Daniele will explore this further. Most of the data are in DBEel, and final issues will be resolved during the meeting.

The Italian data for Sardinia is likely to be for coastal lagoons, and the data are primarily fishing yields. These data could be applied to DemCam and SMEP II, and EDA? Note that the French have eel data for Corsica, and perhaps some of these data could be used as a proxy where appropriate. Daniele will discuss with Eleonora how to get the data to DBEel and the modellers.

The remaining data exchange should be directly between Data Providers (DPs) and Modellers, but Laurent and Cedric should be cc'd so that the data can be included in the DBEel.

The final report of model applications needs a section explaining why certain models could not be applied to certain datasets. For example, the GEM model requires a lengthy time series of data, and therefore could not be applied to the French, English or Spanish datasets. Modellers should draft these texts.

Note that the DBEel does not presently contain any fishery catch data

## **Exchange of Model Results**

We agreed that the minimum results to report should be the '3Bs' from SGIPEE, the wetted area (ha) that produces these biomasses, a geolocation, and the years for which they are produced.

The 3Bs from SGIPEE are:

- Bo - the biomass of the escapement in the pristine state (good recruitment, no human impacts, all habitats).
- Bpost (current) – biomass of the actual escapement in the assessment year
- Bbest – the potential biomass in the assessment year based on recent recruitment and assuming no anthropogenic impacts or stocking, and from all potentially available habitat. (so Bo with current recruitment, or “what could be achieved today by removing all human impacts”).

Modellers should use the European Joint Research Centres Catchment Characterisation and Modelling (CCM) GIS dataset to geolocate their outputs, either by using the identifier of the outlets (WSO\_ID) or the identifiers of the river segments and primary catchments for detailed results (wso1\_id). In cases where aggregations are used (i.e. several river segments together), a reference can be made to that aggregation but a table should be provided linking the individual river segments to the group.

CCM data available from <http://ccm.jrc.ec.europa.eu/php/index.php?action=view&id=23>

Modellers and DPs will have a direct exchange of results during the model applications, to check that the model outputs are appropriate across the whole river basin, and provide an iterative process of adjusting the models to improve the results. These exchanges should be copied to Laurent and Cedric for the DBEel, but only the final results will be input to the DBEel.

Some models produce detailed results at the river stretch scale, but it is not necessary to report these for every year of the time series. Therefore, detailed results should be provided for 1979 and for 2010, as examples of periods of high and low recruitment, respectively, while the 3Bs for the whole river basin/management unit should be reported for every year. For SMEP II and EDA, the detailed results (biomass, density and length structure) should be geolocated to CCM stretches, and then Cedric will illustrate them on maps.

### *The future of DBEEL*

Each POSE member will be provided with a copy of the DBEel at the end of the project. We considered the wider distribution and use of the DBEel after the end of POSE, recognising that the datasets and results would provide a valuable resource for testing future models. However, there are a number of issues regarding ownership and distribution of the data, and the Intellectual Property (IP) rights of the DBEel framework that have to be resolved first.

Depending on the IP rights of the DBEel framework, it might be most appropriate for it to be hosted by the EU Commission. Alternatively, as WGEEL may be one of the main users, perhaps ICES could host the database. However, we noted that ICES has an open data policy and considered this might preclude their hosting the DBEel if data owners imposed conditions on their continued use. We agreed that the question of hosting the DBEel should be addressed during the Data Workshop.

### WP3 Actions

- Daniele will discuss with Eleonora how to get the Sardinia data to DBEel and the modellers.
- DPs and Modellers to exchange data and results directly, but cc Laurent and Cedric.
- All DPs to consider whether their data can be included in an open access DBEel.
- Alan to check the contract conditions regarding the IP rights of the DBEel framework and report to DPs.

### **Virtual Datasets – the Individual Based Model**

We considered some rules for the provision of virtual data to the models.

As the availability or lack of data is a major issue for all model applications, this should be incorporated in the testing scenarios. So, we suggested that the models should be limited by the availability of data, and this could be achieved by supplying 3 amounts of data representing 1. the

typical amount expected in the 'real world'; 2. half this amount; and 3. double this amount. For example, if we would expect 20 electrofishing surveys along a river network of 100 km length, provide virtual data for 10, 20 and 40 surveys.

Criteria for the model testing should include:

- How accurately does the model predict the 3Bs?
- If an impact scenario has been applied to the basin, can the model detect that there has been a change, and can the model 'identify' the impact as explaining the change?

The IBM data should be sent to DBEel in the first instance and then distributed to modellers. This ensures that the IBM only provides one set of data to DBEel, and that where two models require similar types of data, they are supplied with the same data.

Model application should follow the same process as for the real data, with the modeller and IBM DP exchanging notes during an iterative process. The model results should be in the same format as for the real data, above.

Action - Modellers should produce a list of which types of data are required for their model, and the amounts that are available from their river basins.

## **WP4 Model testing – progress and plans**

### ***SMEP II***

Alan presented summaries of SMEP II data requirements, and data available from candidate datasets grouped according to Parameters, Spatial, Local populations and Impacts. SMEP II is designed to be applied at the river basin scale, and therefore could be applied to the English Stour, Irish Burrishoole and Corrib, French Vilaine and Rhone (main river), Spanish Oria, German Elbe and Italian Sardinia datasets. Time and manpower will ultimately limit the SMEP II application.

Most of the data were available for the English, Irish, French and Spanish datasets, and outstanding issues would be discussed on Wednesday.

### ***EDA 2.0***

Celine presented a summary of EDA 2.0.

EDA is based on a river network database, and designed to predict yellow eel densities and silver eel escapement. Version 2 uses the CCM spatial data.

There are four main steps in the model application:

- Relate observed yellow eel presence/absence or densities to descriptor parameters
- Calculate yellow eel density in each river stretch by applying the statistical model calibrated in step 1
- Calculate the overall yellow eel stock abundance, and convert yellow to silver eel abundance based on 5% conversion rate for eels >200 mm
- Estimate a potential silver eel escapement by applying silver eel mortalities

The descriptor parameters considered in step 1 are the number and cumulative height of dams, agricultural land use (from Corine Land Cover database), mean air temperature, 'relative distance' and distance from the sea and source, wetted area upstream, and local river gradient.

EDA is designed to be applied at the Eel Management Unit (EMU) and therefore will be applied to the Brittany and Rhone, the Irish Western, the English Anglian, the Basque, the German Elbe and the Italian Sardinia River Basin Districts.

Celine presented plots of the relationships between eel presence/absence or density against individual habitat parameters. Within the presence/absence dataset there are the expected trends for most parameters, but a complex relationship with the cumulative number of dams which will be explored further. This analysis may be complicated by unrecorded stockings in the past.

Once a French model is complete, they can apply it to the CCM database for any part of Europe, and will do this for all the case studies. Will also 'develop' the model using calibration data from Ireland and Spain, and England.

Conversion from yellow to silver is based on a 5% rate, based on the total yellow eel stock and by number, bearing in mind that the survey bias against small yellow eels (<200 mm) means that they are rare in the model, so really the silver eel conversion is 5% of the eels >200 mm.

#### *DemCam*

Daniele joined the meeting via videoconference from Vancouver. DemCam simulates production in a single compartment and applies the same life history processes throughout. It is possible to apply this to river basin datasets, but only if the entire wetted area is treated as a single compartment.

The model works with recruitment, the stock and escapement, and can derive one from the other two based on information about the standard life history processes. For example, Daniele has back-calculated recruitment for the Irish Burrishoole from the silver eel production time series, and estimates that recruitment now is about 8% of pristine.

#### *German Eel Model*

Rainer has been working on the Irish data. He, Russell and Elvira will finish the discussions during the meeting and then adapt the model over the next 2-3 weeks, then be ready to discuss the tweaks to finish the modelling. It is not possible to use the French, Basque or English data because GEM requires a length time series of input data.

### **Publications**

A number of publications are anticipated from the project, including the descriptions of EDA and GEM, and the Bayesian Framework for Eel Extrapolation (WP5). There are data ownership issues that need to be resolved before the Bayesian model could be made available, but the framework could be published. It was agreed that all POSE-related publications should be seen by Alan before they are submitted, to make sure he is aware of any implications for POSE.

### **Wednesday 19<sup>th</sup> January**

This day was set aside for discussions between DPs and modellers and therefore had no formal agenda or structure. The following summarises these discussions and any resultant actions.



## *SMEP II*

Irish WRBD. The total silver eel catch for the Corrib river basin is derived from the commercial catches in Lough Mask, Lough Corrib and the Galway weir fishery. The Mask and Corrib catches should be raised to account for illegal and unreported catches. The silver eels from Mask tend to be longer and older than those from the remainder of the system. It may be appropriate therefore to simulate a restriction of downstream emigration from this lough when applying SMEP II. The length distributions of the commercial yellow eel fyke net catches are biased by the selectivity of the nets – 28 and 34 cm are the minimum lengths of yellow eels caught in Corrib and Mask in 2008.

German Elbe dataset. The data have been prepared by Erik. There has been stocking for the last 30+ years. There is no local GIS so we will use the CCM data. There are many online lakes, and large variations in eel size, diet and energetics between eels caught along the shorelines and in the more offshore areas. As a result, data from electrofishing the margins are not considered to be representative of the whole eel population. Erik produced a spreadsheet summarising what data were available for the life history parameters, spatial description, local population and impacts.

### Actions

- Alan to annotate Erik's spreadsheet, detailing the required data, and Erik to supply these data.
- Erik to send Alan a map of the Elbe, to help reference the data to locations.

## *EDA.*

Cedric asked if he could get access to the database holding the England eel data, as this would simplify the transfer of data to DBEel. He also asked for the river width data for England, and a description of the relationship used to derive these river width estimates. There are three locations on the Vilaine where the movements of eels have been recorded, so these are sensible places to mark the boundaries between zones for SMEP II. The WSO1-ID codes for these locations are 351366, 351315 and 352646. Similarly the Beaucare Dam on the Rhone is a good boundary between zones, at 331550. Eels would have been expected throughout the Rhone in the past, but their distribution is today limited by many dams. The distributions of dams and electrofishing data for eels will be a good indicator of the present distribution. Cedric will provide a table from the DBEel showing the CCM stretch associated with every electrofishing site. However, the CCM riverline is not perfect and therefore a number of electrofishing locations would appear outside the rivers. These have been corrected as best possible, but it is not perfect.

## E5. POSE Project Meeting / Workshop

Raddison Hotel Stansted

13<sup>th</sup> – 14<sup>th</sup> October 2011

Attendees: Alan Walker (AW), Panayiota Apostolaki (PA), Miran Aprahamian (MA), Russell Poole (RP), Elvira De Eyto (EdeE), Andrew Jackson (AJ), Daniele Bevacqua (DB), Marcello Schiavina (MS), Patrick Lambert (PL), Celine Jouanin (CJ), Laurent Beaulaton (LB), Peer Doering-Arjes (PD), Erik Fladung (EF), Rainer Oeberst (RO), Marine Santurtun (MS), Aizkorri Aranburu (AA), Willem Dekker (WD)

### DAY 1

- Introduction from AW about the end point of POSE- report due by 1st Nov 2011
- Round the table introductions
- RP – update on ICES and EU meetings
  - RP discussed the use of reference points, structure of precautionary diagrams, noting there was place in bubble plots for setting precautionary points
  - WGEEL have come up with alternative bubble plots to satisfy ACOM and ICES precautionary advice, using a mortality of 0.92 which is the equivalent of 40% SPR.
  - If ACOM accepts this new diagram, this is the first time we will have a structure with a set quantity.
  - ACOM are going to officially write to the EU and ask who is doing the reporting after 2012
  - AW and RP attended a meeting in Brussels about reporting. RP gave a quick run through of the precautionary diagram.
  - Meeting on 25<sup>th</sup> OCT to sort out the next version of the template.
  - The working group document is nearly finished, and will go to ACOM in mid November
  - The DCF for eel has been discussed in many of the recent ICES meetings. Opportunity has arisen to influence the DCF, as there will be a workshop in 2012 running in parallel with the salmon group. There will probably be some discussion of the DCF requirements during this meeting
  - Questions : (PA) proportion biomass – explain Biomass (historic) Biomass (current) Biomass (potential) – made the point that sometimes you don't need to quantify the proportion of biomass – it is possible to just model proportion change without any quantities, so by asking for a quantity, the data providers are being asked to produce more data. RP thinks that biomass does need to be reported in quantities, and feels that it is crucial. There is no requirement for providers to itemise the quantities of B in the current template. WD agrees with the point that PA makes
- Patrick Lambert reviewed the tests of assessment models using CREPE (simulated dataset)
  - Principle of constructed reality
  - Steps in use of CREPE dataset
  - Use of CREPE dataset in SMEP (scales were quite different, but the general trend was OK). The variability in the EDA assessment of CREPE has a lot of variability as a

result of recruitment variability. GEM vs CREPE – the trend is OK, and the GEM prediction is orders of magnitude higher than the actual CREPE data.

Bcurrent/Bpristine for CREPE and SMEP and EDA comparison

- PL showed a table with the main distinctions between all the models
- Need to anchor the recruitment index so everyone is using the same value when comparing models
- AW – discussed the SMEP application to CREPE
  - SMEP runs on a river rather than a river district, so the first step was to pick one river, and compress it into smaller zones or reaches
  - Issues to be resolved: Recruit to silver – very different ratios
  - May be a difference between using linear growth vs Von B growth. Also between mortality methods estimates. This will be discussed in day 2.
- RO – Description of the application of GEM to CREPE and Corrib datasets
  - Evaluation of available data; Adaptation of the model; Optimization of model parameters; Evaluation of survey data –very strong effect of natural mortality on the results
  - Plan RO – some discussion of how to get to explore whether it is the model that is wrong or are the discrepancies between CREPE and models a result of interpretation of the data.
  - The crepe data provides the modellers with the possibility of testing exactly how a model works – fill into e.g. SMEP and GEM exactly the same parameters for mortality or growth rate etc, and that is it a better test of the model
  - Is it a spatial scale issue?
- AJ- presentation on the Bayesian Eel No data Model
  - Explanation of production; Modelling approach
  - Ran through previous work – Jessop (2011), Bevacqua (2011), Irish model
  - Part 1 – growth rates – use of t-distributed regression possible because of the Bayesian approach; Growth rate candidate explanatory variables – have to be readily available for any catchment in Europe; Some Bayesian theory
  - Some notes about the model – including weighting the growth rates
  - At sea final model – longitude, latitude etc were the important explanatory variables; Raised some of the outlier issues
  - Part 2 - AJ then described the link between growth rate and silver eel production
  - Mortality – used from Daniele’s model – based on gender, stocking density, initial size, scaling parameters, temperature, growth rate
  - Part 3 – production; Owing to the lack of production estimates, it proves impossible to fit the production part of the model
  - Discussion points:
    - An excellent data set for estimating growth rate
    - Future work – concentrate on getting it right for one catchment
    - Understand the strange observations in these data sets
    - Add in explanatory variables (lagoons)
    - Turn this into a hierarchical model layered by catchment
    - Spatial modelling?
  - In an ideal world, what data would need to be collected to make this model better

Production data

Recruitment data

Data from exploited sites

Fisheries yield data from WGEEL 2008 report and Moriarty and Dekker 1997

- RO -application of GEM to Burrishoole
  - Optimization of model parameters
  - Presented graphs that are in report, showing how the GEM matched the Burrishoole data
  - Some discussion about specific aspects of the exercise
- AW – application of SMEP II to Burrishoole
  - Maps – showing difference between CCM and discovery series
  - Data provision – electro-fishing , escapement, gis etc
  - Scenarios – vary recruitment – anchored to glass eel catch in 1970's
  - Results – SMEP gets the trends right, but numbers wrong; SMEP underestimates
  - Recruitment index; Growth rates
  - Lough Feeagh is probably also a big issue
- LB-database DBEel structure
  - Conceptual model; Attributes; DBEel in reality
  - Some discussion of differing units
  - Some statistics – 18336 observation places, 37300 observations, 430000 batches, 517000 biological characteristics
  - Future of DBEel - Should it be given to the EU? Could this database be a possible framework for DCF data collection or WGEEL or ICES?
  - There was some discussion about keeping the database up to date – would that be the responsibility of whoever takes ownership of the database
  - Agreed to give the structure to the EU, and include the database script as an appendix

## DAY 2

- The group split into two – one group to resolve the issue around the mortality estimates used in CREPE and its applications to GEM, SMEP and EDA; tThe second group discussed the final SWOT analysis of POSE.
  - A SWOT for the Bayesian framework in the SWOT model chapter
  - The modellers in their data requirements section to provide text describing the data tuning process
  - Standardisation of units – wetted area – CCM vs OS wetted area – catchment area or wetted area
  - Cookbook / toolbox is not a possible outcome of POSE – too much uncertainty in models as yet.
  - Make sure we have addressed the eight objectives (MS)
  - Still be completed – executive summary
- Potential for publications arising from POSE
  - World Fisheries Congress; PA - short paper describing the key issues of eel dynamics and key considerations that models need; Many of the models being used have not

been published (DEMCAM, SMEP); Bayesian framework for growth as a predictive tool

- All to examine the authorship of the final report and agree, and provide acknowledgements where appropriate
- The group split into two again
- First group discussed some final model resolutions
- Second group continued with the SWOT analysis – whiteboard exercise
  - The fact that we are still missing  $\Sigma a$  is still a big issue
  - Discussion of why the models used in SLIME and POSE were not used in the 2009 plans?
  - The CREPE dataset must be available for people to use and test their models against
- Plenary discussion
  - Deadlines for editing
  - Any changes arising from this meeting should be submitted by 21<sup>st</sup> Oct (Friday)
  - Comments on the new amendments of report should be in by 26<sup>th</sup> Oct (Wed)
  - Submit to the EU on 1<sup>st</sup> November
  - How is the best way to do these edits? Email, dropbox, google docs - probably dropbox

## Annex F. Contact Details

### Models used in this project

Alan M. Walker, Centre for Environment, Fisheries & Aquaculture Science (Cefas), Pakefield Road, Lowestoft, Suffolk, NR33 0HT, U.K. Tel: +44 1502 524351, Email: [alan.walker@cefasc.co.uk](mailto:alan.walker@cefasc.co.uk)

Céline Jouanin, Cemagref, 50 avenue de Verdun, 33612 Cestas cedex, France, Tel: +33 5 57 89 26 94, Email: [celine.jouanin@cemagref.fr](mailto:celine.jouanin@cemagref.fr)

Cédric Briand, Institut d'Aménagement de la Vilaine, 8 rue Saint James, 56130 La Roche Bernard, France, Tel: +33 2 99 90 94 31, Email: [cedric.briand@lavilaine.com](mailto:cedric.briand@lavilaine.com)

Patrick Lambert, Cemagref, 50 avenue de Verdun, 33612 Cestas cedex, France, Tel: +33 5 57 89 08 09, Email: [patrick.lambert@cemagref.fr](mailto:patrick.lambert@cemagref.fr)

Laurent Beaulaton, ONEMA, "Le Nadar" Hall C, 5 square Félix Nadar, 94300 Vincennes, France, Tel : +33 1 45 14 36 34, Email : [Laurent.beaulaton@onema.fr](mailto:Laurent.beaulaton@onema.fr)

Marcello Schiavina, Dipartimento di Scienze Ambientali Università degli Studi di Parma / Dipartimento di Elettronica e Informazione Politecnico di Milano, via Ponzio 34/5, Milano, I-20133 Italy, Tel: +39 02 2399 9676, Email: [m.schiavina@gmail.com](mailto:m.schiavina@gmail.com)

Rainer Oeberst, Institute of Baltic Sea Fisheries, Alter Hafen Süd 2, 18069 Rostock, Germany, Tel: +49 381 8116 125, Email: [rainer.oeberst@vti.bund.de](mailto:rainer.oeberst@vti.bund.de)

Russell Poole, Section Manager, Fisheries Science Services, Marine Institute, Furnace, Newport, Co. Mayo, Ireland. Tel: 00-353-98-42300, Email: [russell.poole@marine.ie](mailto:russell.poole@marine.ie)

Patrick Lambert, Cemagref, 50 avenue de Verdun, 33612 Cestas cedex, France, Tel: +33 5 57 89 08 09, Email: [patrick.lambert@cemagref.fr](mailto:patrick.lambert@cemagref.fr)

## Data sets used in this project

Miran Aprahamian, Environment Agency, Richard Fairclough House, Knutsford Road, Warrington, WA4 1HG, UK. Tel: +44 1925 542713, Email: [miran.aprahamian@environment-agency.gov.uk](mailto:miran.aprahamian@environment-agency.gov.uk)

Russell Poole, Fisheries Science Services, Marine Institute, Newport, Co. Mayo, Ireland. Tel: +353 98 42300, Email: [russell.poole@marine.ie](mailto:russell.poole@marine.ie)

Ciara O'Leary, Inland Fisheries Ireland, Swords Business Campus, Swords, Co. Dublin, Ireland. Tel: +353 1 8842 600, Email: [ciara.oleary@fisheriesireland.ie](mailto:ciara.oleary@fisheriesireland.ie).

Peer Doering-Arjes, Institute of Inland Fisheries (IfB) Potsdam-Sacrow, Im Königswald 2, 14469 Potsdam, Tel: +49 33201 406 28, Email: [peer.doering-arjes@ifb-potsdam.de](mailto:peer.doering-arjes@ifb-potsdam.de)

Erik Fladung, Institute of Inland Fisheries (IfB) Potsdam-Sacrow, Im Königswald 2, 14469 Potsdam, Tel: +49 33201 406 14, Email: [erik.fladung@ifb-potsdam.de](mailto:erik.fladung@ifb-potsdam.de)

Laurent Beaulaton, ONEMA, "Le Nadar" Hall C, 5 square Félix Nadar, 94300 Vincennes, France, Tel: +33 1 45 14 36 34, Email : [Laurent.beaulaton@onema.fr](mailto:Laurent.beaulaton@onema.fr)

Laurent Beaulaton, ONEMA, "Le Nadar" Hall C, 5 square Félix Nadar, 94300 Vincennes, France, Tel: +33 1 45 14 36 34, Email : [Laurent.beaulaton@onema.fr](mailto:Laurent.beaulaton@onema.fr)

Eider Andonegi, AZTI-Tecnalia, Txatxarramendi Ugarte a z/g- 48395 Sukarrieta, Bizkaia, Spain. Tel: +34 94 657 40 00 FAX: +34 94 657 25 55, Email: [eandonegi@azti.es](mailto:eandonegi@azti.es)

Estíbaliz Díaz, AZTI-Tecnalia, Txatxarramendi Ugarte a z/g- 48395 Sukarrieta, Bizkaia, Spain. Tel : +34 94 657 40 00 FAX: +34 94 657 25 55, Email: [ediaz@azti.es](mailto:ediaz@azti.es)

Alessandra Cannas, Via Mameli 115, 09123 Cagliari, Italy, Tel: +39 070655269, Email: [alessandra.cannas@istruzione.it](mailto:alessandra.cannas@istruzione.it).

## Annexe G. Implementation of DBEEL

DBEel has been implemented in PostgreSQL software<sup>1</sup> under the 9.0 version. The Postgis<sup>2</sup> add-on under the version 1.5 has also been used, as well as the uuid-osp additional functions<sup>3</sup>.

The whole SQL file for creating the database as the structure is implemented the 12/08/2011 is provided as a separated file (Annex\_G\_bdeel\_structure20110812.sql). This script can be viewed using any word processing package, but as it is about 125 pages in MS Word, the original .sql file is provided separately.

<sup>1</sup><http://www.postgresql.org/>

<sup>1</sup><http://www.postgis.org/>

<sup>1</sup><http://www.postgresql.org/docs/9.0/static/uuid-osp.html>

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<sup>1</sup><http://www.postgresql.org/>

<sup>2</sup><http://www.postgis.org/>

<sup>3</sup><http://www.postgresql.org/docs/9.0/static/uuid-osp.html>