# 3 International stock assessment and data needs

## 3.1 Introduction on stock assessment and data needs

The European Union has decided on a protection and restoration plan (Eel Regulation) in 2007, aiming at the protection of 40% of the silver eels, relative to a situation without human influence. At the heart of the Regulation is the obligation for all Member States to develop a (national or river basin specific) management plan for the eel stock and fisheries, aiming at the agreed 40% target. Each management plan should contain an assessment of the current status of the local stock, a description of future monitoring and registration of catch and fisheries for future assessments of the stock and anthropogenic impacts.

The WGEEL considers its tasks (ICES and EIFAC ToRs) to assess and evaluate the overall status of the stock, and the impact of protection measures taken. There is an apparent overlap with the obligation in the Eel Regulation, to report on the status of the stock in individual Eel Management Units, and with the evaluation by the Commission. However, the assessment of the working group will focus on the total population, independent of the split over jurisdictions and management units. Only where the biological processes are inherently spatially diversified, will the assessment of the working group go into disaggregate analyses.

This chapter will elaborate the concepts of an international assessment of a regionally managed stock (Section 3.2), and derive criteria for a minimally required dataset on eel (Section 3.3).

## 3.2 International stock assessment

### 3.2.1 International management and stock assessment

The EU Regulation on eel sets a common target for the escapement of silver eels, at 40% of the natural escapement in the absence of anthropogenic impacts. In accordance with the precautionary advice provided by ICES (2002), it is assumed that a stock recruitment relationship exists. Member States are obliged to implement protective measures to achieve the escapement target, and should provide a time schedule for the attainment of this target. This time schedule is certainly much more determined by the slow biological restoration of the stock (decades; Åström and Dekker, 2007), than by the time required to implement the protection measures completely (years?). The Regulation sets no limit on the time frame for restoration. Implicitly, this rules out the hypothesis that the stock–recruitment relationship is determined by depensatory processes, as tentatively found in historical data (Dekker, 2004; ICES 2007). As an alternative to the depensation hypothesis, it has been hypothesized, that the decline of the stock might have been caused by climate factors (Chapter 7 of this report), pollution or parasitism (chapter 6 of this report), and others acting in the oceanic phase.

Noting that the EU Eel Regulation has set targets for the quantity (biomass) of silver eels escaping from the continent, and obliges Member States to take protective measures primarily focusing on the quantities escaping, but has not set targets and does not oblige to take actions with respect to other processes (related to silver eel quality, or climate change) in relation to eel management (if possible), the international assessment of the status of the stock will presently focus on the dynamics of stock in numbers and quantities, and on the effect of protection and restoration measures taken. This does not, in principle, rule out potential effects of other factors, including silver eel quality and/or climate factors. However, since the mechanisms involved have not been cleared up, and the quantitative impact on the stock is unclear, there is no way forward to include these aspects in international stock assessment at this moment in time. Further research will be needed, to elucidate the processes, to quantify the impacts, to find mitigation measures, to advise management targets, and to assess the net effects of measures taken on the eel stock. Until that has been done, prime focus in the stock assessment will necessarily rest with "classical" fish stock assessment, which for the eel case, will be complex enough.

Under the EU Eel Regulation, an international assessment will be required of the population-wide status of the stock, and an assessment of the impact of the management measures taken. The Regulation focuses on stock dynamics in terms of quantities and biomass and thus the assessment leaves aside scientific debates on the impact of spawner quality and/or climate factors. A decision tree diagram for this assessment is presented in Figure 3.1. The indicated steps are elaborated in the text below;

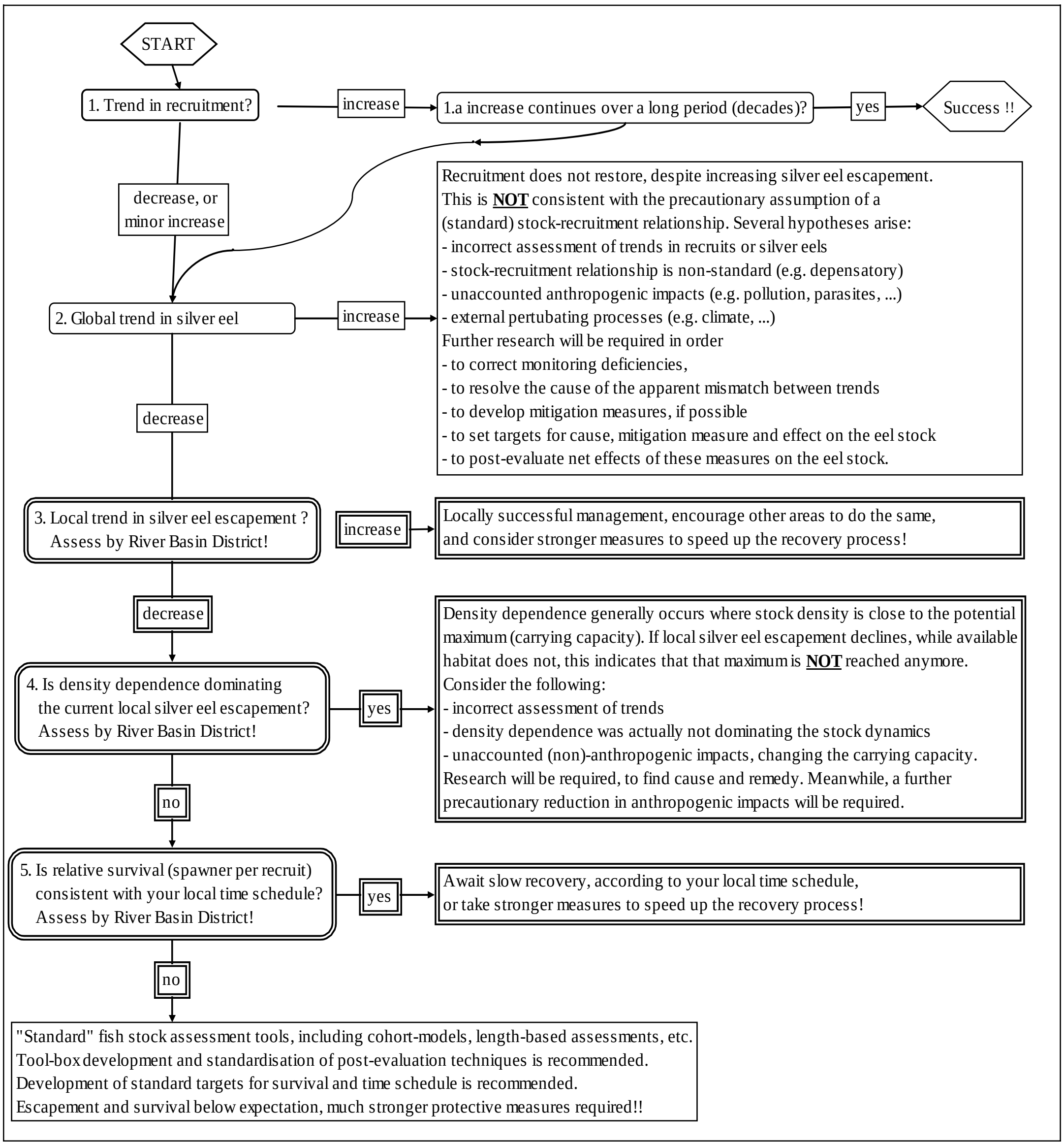


**Figure 3.1: Decision tree for international assessment of the impact of protective measures taken under the EU Eel Regulation. International issues are depicted in a single-lined box, whereas River Basin Specific issues are in a double-lined box.**

### 3.2.2 Only recruitment and escapement trends?

Taking a superficial view on first examination of the task of international stock assessment, it might appear that the time-series data on spawner emigration and glass eel recruitment are the only data items of information essential to international assessment of eel stock and recruitment. This view, however, ignores the reality of the current and probable future situation. Only if recruitment were to recover rapidly following measures to increase spawning stock, resulting in confidence that recovery is underway, would these two data items suffice. Such a rapid recovery is an unlikely scenario, given that our ability to increase spawning stock escapement significantly will be limited for at least an eel generation, as a consequence of the past 15 to 25 years of low recruitment yet to feed through to spawner emigration (Chapter 2 of this report). It is quite probable, therefore, that recruitment will continue to decline for some time, and it will be almost unavoidable that silver eel escapement will also decline considerably further for at least some years. The effectiveness of protection and restoration measures taken under the EU Eel Regulation will therefore have to be judged on a relative scale: the relative improvement of survival from recruit to silver eel. This necessitates the analysis of the full continental phase of the life cycle.

### 3.2.3 Issues of time-scale

The principal objective of WGEEL at its future meetings will be assessment, renewed annually, of the state of the stock and recruitment at an international level. The desired objective of current management is clearly that measures taken to protect and enhance spawner escapement result in increased recruitment. The time-scale for full evaluation of such success is long, and for assured confidence that recovery is underway, any recovery will have to be successfully tracked through the generations, that is: over decades.

### 3.2.4 If recruitment continues to decline

Should recruitment not respond positively to increased spawner biomass, and continue to fall whereas spawning-stock biomass is rising, then there are other factors operating than those included in the assumptions (that eel will follow classical stock–recruitment relationships).

Where such conclusion is reached, at any point in the assessment and study of eel, it would be evident that unknown factor(s) are acting on the stock–recruitment relationship. This brings in possibilities such as a problem in oceanic processes affecting migration, eel “quality” factors affecting spawning ability, genetic issues, or a new and unforeseen problem resulting in depensation in the S-R process. These scenarios would all force an urgent search through research programmes on possible additional causes of decline, which is of course an option at any stage where new evidence of detrimental factors arises. These “new” problems, however, have always to be researched through a process involving data gathering, correlation, quantification of cause and effect, development, proposal and adoption of mitigation measures, and post evaluation before they can be fully built in to the assessment of S-R or R-SSB processes. It is therefore necessary that the “new” lines of potential impact research are continually progressed through research programmes alongside the annual stock assessment process, so that when and if numerical estimates of their impact are available, these can be taken into account.

If recruitment does not respond to spawner enhancement measures, and spawning stock continues to decline, then the assessment process is required to investigate biological and mortality processes at a spatially disaggregated level. In principle, the analysis could proceed, at a biologically meaningful disaggregated level. In practice, however, the RBD level will be much more easily achievable. At this level, management measures have been taken, and data on stock, fisheries and other anthropogenic impacts have been gathered. Indeed, the probable situation over the coming two decades is at best continued low spawner emigration protected to some degree by measures to be taken under management plans required the eel regulation, with glass eel recruitment at best displaying a slow recovery but perhaps continuing its decline. Management plans may fail to generate any increase in spawners, some through no fault of the plans but simply as a consequence of the history of low recruitment, and some through inadequacy in the plan. In this scenario, it will become necessary to carry out a spawner-per-recruit analyses at the international level (that is probably the simple sum of river basin specific analyses) to distinguishing between these two possible causes of unpredicted low spawner production. This analysis will require access to data to examine processes operating at least at the eel management unit, and preferably the river basin level.

## 3.3 Data requirement

An internationally coordinated international stock and recruitment assessment for European eel has a minimum data requirement, which is not yet met. The data needed for future international stock–recruitment assessment are a minimum of:

1 ) Escapement estimates from all Eel River Basins, in absolute terms (biomass and numbers, by sex), combined with

2 ) Recruitment indices indicative of recruitment strength over the whole distribution area.

### 3.3.1 River Basin vs. international uses of data

The sum of the escapement estimates over the distribution area provides a proxy estimator of the spawning stock size, whereas recruitment indices quantify the offspring. The combination of spawning stock size and recruitment index facilitates assessments of stock status and analysis of the stock–recruitment relationship and potential effects of climatic factors on the oceanic life phase.

The analysis of the stock dynamics in the continental phase, i.e. a spawner-per-recruit analysis, requires data from the continental phase, which resides within national waters, within Eel Management Units (EMUs). Since the biological characteristics, as well as the anthropogenic impacts on the stock vary from region to region, a single unified assessment of the status of the stock will not be feasible, other than on an EMU by EMU basis.

Neither the Eel Regulation, nor the Water Framework Directive programmes oblige Member States to make the basic data available, though they do contain an obligation to report on the results to the Commission. The Data Collection Regulation, in contrast, does require Member States to make data available upon request, but no central database exists. A future WGEEL might have to specially request these data from the Commission. As indicated above, partial spatial coverage may allow for an analysis of trends in recruitment, but neither the assessment of the trend in silver eel escapement, nor the assessment of the relative survival over the continental life stages, will be feasible. A formal requirement, and a practical procedure to present and store the data, will have to be developed. Development of protocols, exchange procedures and databases will not be feasible within the framework of the international assessment working group.

### 3.3.2 Use of yellow eel data

Therefore, data on the growing yellow eel phase are not directly applicable to the first level of an international scale stock assessment. They are, however, essential to individual member states, or regions, for example as inputs to modelling silver eel escapement, or for providing interim data check points during the long growth term between recruitment and silver eel production. If the national or regional stock assessments are to be checked at an international level, the data on which these are based must be available in an accessible form.

### 3.3.3 The EU Eel Regulation

The EU eel recovery regulation requires specific national actions including the gathering of some eel data, and the supply of these data to the EU Commission upon request. It does **not** specify or require that this information is directly available to the WGEEL or to any organization except the EU commission. Furthermore, the data to be gathered as part of the management plan and subsequent reporting to EC under the stock recovery regulation is to be supplied to the EC at relatively long intervals of at least three years. The reporting cycle starts with the detail of management plans by the end of 2008, with subsequent reporting every three years, reducing in frequency to every six years after 2021. The Commission itself will make its first report to the EU Parliament in 2013.

Notwithstanding the fact that there is no built-in obligation to report these data to the WGEEL for stock assessment, the intervals in the reporting cycle under the EU Regulation are far too long to enable any rapid progress by WGEEL. For an assessment working group to make significant progress toward bringing eel in line with other international species stock assessments, annually updated data are required. The cross-compliance requirement between the recovery regulation and the CFP fishery data collection regulation obliges countries to make some data available annually. However, the DCR does not (yet) cover all data sources required for an assessment of the status of the stock, either at EMU or wider scales.

### 3.3.4 Checklist of actions required under the Eel Regulation and associated guidelines

Where data may be useful to international stock assessment this is displayed in **bold text**.

- Establishment of management plans by country or other eel management unit by end 2008, including:
- A list of management units and authorities responsible.
- An inventory or individual basins in each management unit.
- Justification for the use of a national scale plan if this option is selected.
- Maps revealing eel management units in relation to WFD river basin districts.
- **Annual catch, if fished, in Kg for each RBD of glass, yellow and silver eel. (this is not included in the regulation itself but is included in the Commission implementation guidelines).**
- Quantitative and qualitative description of eel fishery units.
- A list of fishers, licences, vessels licensed to local and EU waters, plus auctioneers and licensed dealers.
- **Quantitative and qualitative descriptions of eel fishery effort reflecting local situation and any reductions imposed.**

- A quantitative description of recreational eel fishing, i.e. numbers of fishers and their catches of eels.
- **Statement of which optional method(s) is used to define silver eel escapement of target 40%.**
- **A description of the silver eel 40% escapement target mode of measurement system used including its precision and accuracy.**
- A description of habitat condition, including non fishery mortalities e.g. caused by pollution, migration obstacles (**quantify this mortality if possible**).
- **An indication of the proportion of each life stage affected by contaminants, pathogens, parasites and degree of contamination.**
- **Qualitative and quantitative descriptions of past restocking and any intended as part of the management plan, with stocked areas.**
- **A quantitative estimate of how stocking, if to be used, will contribute to achieving the 40% escapement.**
- The proportion of captured less than 12 cm eel to be used for restocking.
- **Actual or estimated escapement relative to the 40% target, at time of plan submission (2008) with description of estimation methods used.**
- Price monitoring for glass eel markets.
- Description of the sampling system for catches and effort concerning all life stages of eel, with regard to Regulation (EC) No 1639/2001 (DCR).
- Measures to identify origin and traceability of live imports and exports.
- Determination that eel imported and exported from territory are captured within national (EMP) and international (CITES) rules.

In summary, this checklist identifies several items of potential use to future working groups, assuming that the WGs have access to all data, preferably in the year produced, rather than having to wait for the reporting cycle. By far the most relevant data for international use will be the silver eel potential and actual escapement estimates.

There are, however, very significant deficiencies in this data source as an aid to international stock assessment. Perhaps the most obvious gap is the failure of the regulation to secure a fishery-independent glass eel recruitment dataseries. The reliance on catch monitoring focuses the relevant part of the regulation on commercial glass eel fisheries, which may change markedly, resulting in loss of individual dataseries. As outlined above, the reporting cycle of three years is at intervals too long for any rapid progress to be made on international scale stock assessment. Many of the data highlighted, while of supporting interest, are not core requirements. The absence of a requirement for eel quality data are noted.

### 3.3.5 Data Collection Regulation

The cross-compliance link between the Eel regulation and the DCR process is a useful provision for stock assessment purposes. The DCR driven data provision is, however, dependent on continuation of commercial and recreational eel fisheries. There is no requirement for any fishery-independent eel sampling in the DCR or for any sampling to continue where and when fisheries close. Continuation of commercial eel fishing is far from guaranteed given the continuing downward trends in catches, the possibility of approaching economic extinction, and the probability of widespread cuts in eel fishing activity as a consequence of MS or RBD scale failure to meet the "40%" silver escapement targets required in the eel regulation.

Even while the DCR does apply and forces data collection, the minimum prescribed sampling is unlikely to provide sufficient data to compile a meaningful international scale eel stock assessment, as it does not contain yellow eel surveys. Although there will be some silver eel data where fisheries still exist, most DCR data will be on yellow eel fisheries, and as such will be of indirect value to international stock assessment. Silver eel fisheries are also likely to be the first target for closure when escapement targets are failed.

According to the DCR minimum stipulation for data precision level, the "fallback" option is to measure 100 eels for every 20 t landed. A dedicated workshop on national data collection of European eel (Dekker *et al.*, 2005) concluded that "… one sample per 20 t catch … was found to be inadequate …" and recommended that "15 samples per life stage, per management unit would be more appropriate". This workshop also stated that "The number of individuals per sample for length analysis was examined and there has been no analysis to date determining the precise levels required. Common practice would indicate that 100 individuals per sample may not be adequate for length and this should be increased to 200 per sample. SGRN (STECF) have strongly endorsed this recommendation in its December 2007 meeting. However, for some RBDs with small fisheries, the DCR sampling requirement exceeds the typical annual catch of yellow or silver eel, but as the EU Eel Regulation constitutes an international recovery plan, normal exemption rules do not apply.

The DCR on its own will not provide a framework to estimate the size of the spawning stock as the programme does not provide estimates of eel abundance in small fisheries or in those waters not fished.

### 3.3.6 Recruitment dataseries are not secured

EU concerted action 98/076 (Dekker, 2002) brought together the Europe-wide dataseries of recruitment sampling which now form the basis of the recruitment data reported annually to this WG. It was concluded at the time that better coverage was needed and proposals were made to establish new sites. Only two of these new sites (research sites in Greece) have been started, and some of the formerly active sites are now effectively stopped as a consequence of their dependence on fisheries now not commercially viable or a lack of glass eel produced for restocking.

### 3.3.7 Water Framework Directive

The WGEEL has noted on many occasions that the requirement for MS to monitor eels as part of inland fish populations under Water Framework Directive provisions may also aid stock assessment. Such monitoring is likely to gather some data on yellow eel and as such will be a data input to silver eel output models. However, given the broader aims of the Water Framework Directive, there is a high risk that the monitoring related to the WFD will be inadequate for the assessment of the eel stock. Inadequate spatial coverage, low selectivity for eel, underreporting actual eel catches and non-reporting for eel, have been observed.

### 3.3.8 Data availability for international analyses

Table 3.1 summarizes the assistance that currently active initiatives, including the eel regulation, DCR provisions, and WFD monitoring, may bring to international stock assessment. It is concluded that these, while welcome, will not provide any rapidly available source of data for a full international eel stock assessment. This objective can only be achieved by the establishment of nationally maintained database, made available for international compilation, of the key stock descriptors. These descriptors are emigrating silver eel numbers, biomass and sex ratio, and recruitment in terms of glass eel or young of the year numbers and biomass. The component and compiled data must be annually updated to enable examination of any stock–recruitment relationship. Only when such data exist will it be possible to bring eel population and stock- recruitment assessments to the level given to most other major internationally exploited fish species.

The list of data elements and supply in Table 3.1 includes the EMU or RBD level data as a requirement, over and above the simple need for aggregated total spawner emigration and glass eel recruitment indices. In almost all cases, these data do not currently exist and new dataseries need to be commenced, with international coordination ensuring a compatible approach end allowing future analyses of the disaggregated individual area components of the aggregated spawner production per recruit relationship.

**Table 3.1: Summary of potential data provision as required by EU and other international legislative instruments, and WG data requirements for post-evaluation of the Regulation.**

| Data Element | EC Eel recovery regulation 1100\2007 | Guidance document for preparation of EMPs | DCR | WFD | CITES requirement (if international trade exists) | Adequate coverage? Ok Not ok. | Required for stock–recruitment analysis (ocean) | Required for survival analysis (continent) | Not in assessment (further research required). |
|---|---|---|---|---|---|---|---|---|---|
| EMUs and River Basins | Y | Y | | Y | (Y) | Listavailable 2009 | | + | |
| List commercial Fishermen | Y | | | | (Y) | | | | |
| Catch by recreational fishers | Y | | Y | | | Tri-annual insufficient | | + | |
| List of primary sellers | Y | | | | (Y) | | | | |
| Traceability in trade | Y | Y | | | Y | | | | |
| Fishing Capacity | | Y | Y | | (Y) | | | | |
| Silver eel escapement | Y | Y | | | (Y) | Tri-annual insufficient | + | + | |
| Potential SE escapement | Y | Y | | | (Y) | One off in 2008/9 | + | + | |
| Fishing effort by métier | Y | Y | Y | | (Y) | From DCR | | + | |
| Landings, glass eel | Y | Y | Y | | (Y) | From DCR | | + | |
| Landings, yellow eel | | Y | Y | | (Y) | From DCR | | + | |
| Landings, silver eel | | Y | Y | | (Y) | From DCR | | + | |

| Data Element | EC Eel recovery regulation 1100\2007 | Guidance document for preparation of EMPs | DCR | WFD | CITES requirement (if international trade exists) | Adequate coverage? Ok Not ok. | Required for stock–recruitment analysis (ocean) | Required for survival analysis (continent) | Not in assessment (further research required). |
|---|---|---|---|---|---|---|---|---|---|
| Catch composition -Length | | | (+) | | | From DCR | | + | |
| Biological sampling for length, age, sex, maturity | | | + | (Y) | | DCR, but only where fisheries exist | | + | |
| Recruitment surveys | | | | | | Incomplete, and no obligation! | + | + | |
| Yellow eel surveys | | | | Y | | WFD, low coverage and detail | | + | |
| Silver eel "surveys" | | Y | | | | Tri-annual insufficient | + | + | |
| Hydropower mortality – No Stations | | Y | | Y | (Y) | EMP ,WFD Hydromorph data | | + | |
| Hydropower mortality | | Y – If info available | | | (Y) | Not for all sites | | + | |
| Predation Losses | | Y – If info available | | | (Y) | only partial coverage | | + | |
| Eel Quality data1 | | Y | | | | Only local data | | + | |

**[1] e.g. fat content, contaminants, parasites and diseases.**

**Y =Required as a primary function; (Y)=Required as cross-compliance; + =Adequately covered; (+) =Partially covered but inadequate; entries in bold indicate data deficiencies, while entries in italics meet requirements. Eel quality includes pollution, parasites, pathogens and fat levels.**

## 3.4 Stock assessment vs. research needs

The EU Regulation on eel aims at the restoration of the spawning stock and recruitment. Implicitly, it assumes that a stock–recruitment-relation (of the standard type) exists for the total stock. In Figure 3.1, a decision tree diagram is presented, in which the international assessment of the state of the stock and of the impact of protective measures under the EU Regulation are evaluated, on the basis of trends observed at the global and local level.

The EU Eel Regulation has set targets for the quantity (biomass) of silver eels escaping from the continent, and obliges Member States to take protective measures primarily focusing on the quantities escaping. No targets have been set with respect to other processes (e.g. related to silver eel quality, or climate change) in relation to eel management (if possible). The international assessment of the status of the stock therefore focuses on the dynamics of stock in numbers and quantities, and on the effect of protection and restoration measures taken.

However, the evaluation process depicted in Figure 3.1 (left hand column), provides diagnostics at several points in the evaluation process, judging the adequacy of the focus on quantities escaping only. When these diagnostics indicate a deviation from expectation, further research will be required to clear up the processes, to quantify their impacts, to find mitigation measures, etc. The right hand column of the decision diagram of Figure 3.1 presents a bare skeleton for the decision processes for these cases.

The final two columns in Table 3.1 reflect the current state of development of data and quantitative knowledge of how they affect processes, separating those data items essential now for database building to feed SPR analyses from those where there may be an impact on eel biology but where current and further research programmes need to be completed to quantify impacts and to allow these to be incorporated into mathematically based analyses of stock and recruitment processes.

## 3.5 Stock assessment

### 3.5.1 Mortality based management targets

If and when recruitment continues to decline and silver eel escapement is not improved (which situation is quite likely to occur in the coming years) a critical assessment of the stock status will be required for each River Basin District, indicating whether or not the targets of the EU Eel Regulation have been met. The target of the Eel Regulation has been set in terms of silver eel escapement biomass (40% in relation to a notional pristine production). There are many areas where that target can not be reached in the foreseeable future, as a consequence of the low recruitment in recent years, even if all anthropogenic mortality would have been removed immediately. Additionally, a phased implementation of protective measures might slow down the recovery in the earlier years following implementation of the Regulation.

However, the Regulation also requires Member States to specify a time schedule for the attainment of the target. The Regulation does not specify what time schedules will be accepted. Restoration times are more likely to be in the order of decades or centuries, than in terms of years (Åström and Dekker, 2007); if total anthropogenic mortality remains above a critical threshold (fishery mortality $F$ plus other anthropogenic mortality H is 0.08 in that analysis), no long-term recovery is expected. Preliminary re-assessment of the time till recovery for specific parts of the distribution area (notably the southern areas with higher growth rates), presented during the working group meeting, confirms a decadal or centennial recovery period, and a threshold mortality level for long-term recovery, though the results differ in absolute values.

Since the Eel Regulation biomass target is not achievable in the near future in many areas, the mortality threshold for recovery is expected to represent the effective target to which the stocks, the anthropogenic impacts and the protection measures will have to be judged. The implicit character of this mortality threshold (being derived from the time schedule, as an unacceptable "keep steady" limit) pleads for the derivation of an explicit mortality target, corresponding to the time schedule requirement and/or the biomass target of the EU Eel Regulation. A general, area-independent target is recommendable, e.g. %SPR. Whether this index of life time mortality actually suffices for eel, needs to be investigated.

### 3.5.2 Density dependence and stock assessment

The long continued and widespread decline of the European eel stock has led to adoption of a protection and recovery plan, based on classical concepts in fisheries biology for precautionary reasons. This concerns, first and foremost, the assumption of a classical stock–recruitment relationship in the oceanic phase. In its continental phase, however, the eel is scattered over a multitude of small water bodies (Dekker, 2000), in almost all EU Member States and surrounding areas, often under local management. Biological characteristics of the continental waters vary, both at short distance (e.g. from the coast, via rivers and lakes, to headwaters, marshes and ditches) and between geographical areas (from productive lagoons in the Mediterranean, via densely populated rivers in the Bay of Biscay, to extensive cold waters in the Baltic, producing low densities of large old females). Because of the wide variety of ecosystems in the continental phase, no single uniform approach to protection and assessment will suffice. Some local stocks will be adequately represented by classical population models such as life table models, but others will not. Perhaps the most conspicuous deviation is found in places where density-dependence dominates the local stock dynamics. Where this occurs, an increase in recruitment, as strived for by the recovery plan, will not result in a (proportional) increase in the stock and in the silver eel escapement. Where and when this occurs, the classical models of (density independent) stock dynamics will not be applicable. Loss of production potential can occur in these waters as a consequence of habitat loss, or loss of accessibility (migration barriers). Otherwise, the presence of density-dependence indicates that the stock is at or, close to, its maximum density (carrying capacity), and restrictions of anthropogenic impacts will probably not increase silver eel escapement very much. Consequently, management actions should primarily focus on mitigation of habitat loss. However, we do not know in how many rivers density-dependence is evident, and the continued decrease in recruitment will decrease their number over the years. Where and when density-dependence is insignificant, classical concept in fish stock dynamics, such as life time survival, spawner per recruit, and maximum sustainable yield can be applied. Derivation of (standardized) criteria for density-dependence, and adaptation of (standard) fish stock assessment models to the peculiarities of the eel for density independent cases is required.

### 3.5.3 Assessment tools

The EU Eel Regulation obliges Member States to assess the current state of their stocks, and to assess the expected impact of proposed management actions. The international stock assessment, as discussed here, will post-evaluate the status of the stock, and the net effect of management measures taken. That is: the focus is on the actual state of the stock, rather than on expected impacts. The field of fish stock assessment is particularly well developed for marine fish stocks, including techniques such as cohort analysis, length frequency based assessments, survey based assessments, etc. Existing experience in post-evaluation assessment techniques for eel fisheries is extremely limited (see Dekker *et al.*, 2006 for an overview). Taking advantage of the experiences in marine fish stock assessments, the construction of adequate post-evaluation techniques for eel stocks is an achievable challenge. In contrast with "standard" marine fish stock assessment techniques, anthropogenic impacts other than fisheries (e.g. predation, hydropower, eel quality), the spatial distribution of local stocks within river systems, migration and migration barriers should also be taken into account. It is recommended to develop these tools internationally, making optimal use of available expertise and funding, and involving data and experts from various geographical areas.

The adoption and implementation of the EU Eel Regulation will set an unprecedented breakpoint in eel stock management, and will it is to be hoped lead to a major breakpoint in stock trends. Consequently, the application of the above mentioned post-evaluation assessment techniques will have to cope with unprecedented datasets. It is therefore suggested to explore the use of constructed reality, that is: to apply the tools being developed on data derived from (other) simulation models.

## 3.6 Conclusions and recommendations for Chapter 3: International stock assessment and data needs

The absence of any internationally driven requirement to maintain a recruitment dataseries needs to be corrected, with reference to the recommendations of the EU contract 98/076: Establishment of a recruit monitoring system for glass eel.

Internationally coordinated eel recruitment monitoring should be included in the requirements for the DCR.

The WGEEL notes that for future meetings it will need:

- The means to compile data on spawner emigration and glass eel recruitment,
- The means to assess RBD level spawner output per recruit relationships with the full access to EMU level data that entails.

The WGEEL further notes that:

- Current legislative instruments including the Eel Regulation, DCR, CITES and WFD do not, either individually on in combination, contain sufficient provisions to ensure adequate data supply for such assessments.
- There is an urgent need to develop assessment and post-evaluation tools adapted to the eel case.

# 4 Assessing stocks and management actions

## 4.1 Background theory on population dynamics

### 4.1.1 Introduction

The reproductive process is one of the main mechanisms that controls and maintains fish populations. In fisheries science, the phase from adult spawning stock to new-born recruits contributing to the stock is known as Stock-Recruitment (S/R) relationship. It is the evolutionary mechanism by which fish stocks "buffer" the effect of varying food and spatial resources. The S/R relationship is most often explored by examining the empirical relationship between the spawning stock size (or its proxy) and the subsequent recruitment output which results from a complex chain of events through spawning, ova deposition and larval and juvenile growth and survival. In fish stocks, the S/R relation is often the main resilient mechanism buffering the exploitation mortality.

The mechanisms that determine the S/R relationship can be categorized as density-dependent and density independent. Density independent mechanisms imply that the individual chance of survival for a youngster is independent of its parent's stock size and the number of eggs produced, giving rise to a linear relationship between the spawning stock size and the number of recruits produced across the range of spawning stock sizes. This model must have limits since no population can increase indefinitely given that resources are finite, and fully density independent relations are not observed in practice. At high spawning stock size, compensatory mechanisms ultimately limit population size by maintaining some ceiling on the level of recruitment, i.e. density-dependence becomes dominating. Several mathematical models have been used to describe the shape of S/R models (i.e. Beverton-Holt, Ricker) but these all take a similar general shape at low stock sizes and largely only differ in the upper ranges of stock size, which is of little concern for depleted stocks.

Figure 4.1 describes a theoretical S/R relationship of the Beverton-Holt type. The solid line describes the relation between the number of spawners and the subsequent number of offspring (recruits). This has an almost density independent phase (nearly linear) at low stock density (spawning stocks of 0 to 10, recruitment of 0 to 40) and an upper density-dependent phase, when the curve levels off (see above).

It is relatively simple to understand this relationship for local stocks such as salmon or sea trout where the spawning effort and juvenile production takes place in individual catchments and where density-dependent factors such as space for spawning and food availability are clearly finite resources. It is much more difficult to envisage how this might operate for eel which has an oceanic spawning and larval phase, given the lack of knowledge of the spawning and early life history of the eel in the Sargasso.

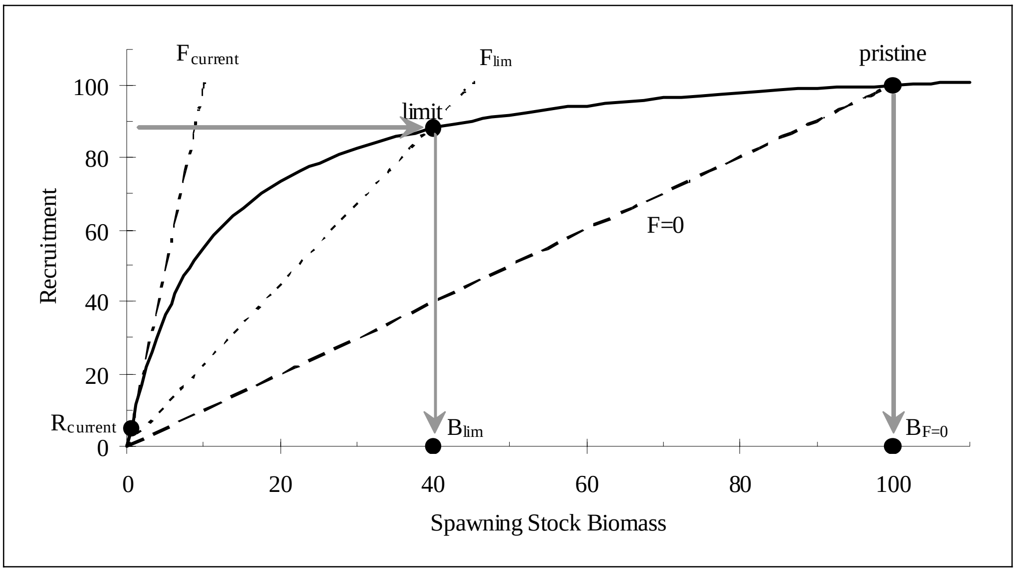


**Figure 4.1: Hypothetical Stock-Recruitment relationship, showing a Beverton and Holt-type relationship, the solid line indicates what recruitment is produced at what spawning stock size; the broken lines indicate what spawning stock can be derived from a given recruitment, at no fishery (F=0, dashes line), at maximal, just sustainable fishery ($F_{lim}$, dotted curve) and current non sustainable fishery (and other anthropogenic sources of mortality) ($F_{current}$, dot-dashed curve). Both Recruits and Spawning Stock Biomass are given in arbitrary units. The EU Regulation sets the minimum target at 40% of the pristine spawning-stock biomass, which will keep recruitment close to its maximum, but on the brink of impaired recruitment. The intersections between the two types of curves determine equilibrium biomasses (densities).**

So, population dynamics and resulting equilibrium levels can be analysed through the use of curves for SSB->R (from Spawning Stock Biomass to Recruitment) and R->SSB (from Recruitment to Spawning Stock Biomass) (see Figure 4.1) where:

- Recruitment in this context is assumed to be the biomass (or number) of glass eels that successfully arrive to continental waters after having survived juvenile density-dependent mortality in the oceanic phase. An alternative could be to define recruits as a somewhat later stage like: glass eels settling (or elvers) in continental waters, and thus include the possible local density-dependence in the early processes when glass eels arrive at the continent.
- Spawning stock biomass is the magnitude of the effective spawners, i.e. the ones that are successfully reaching the Sargasso Sea and actually spawning.

Equilibrium points correspond to intersections points between the two types of curves.

The SSB->R curve depends upon oceanic factors such as spawner, success, currents, food availability, etc, whereas the R->SSB curve depends upon mortality cumulated during continental lifespan. Particularly, mortality rates *F+M* (anthropogenic and natural) cumulated in the lifespan (from glass eel to spawner) determines the slope of the R->SSB relationship and consequently the equilibrium level. Higher levels of mortality rates determine equilibrium points corresponding to lower values of both R and SSB.

Note that spawner quality might be explicitly included in the SSB->R relationship as an additional mortality considered that "bad spawners" die before spawning, but after leaving the continent, or simply produce less offspring.

### 4.1.2 Eel stock and stock decline

In recent years[1], the development of the precautionary approach in fisheries management and the exploitation of stocks have received much attention along with the development of fisheries management tools and the provision of scientific advice. The precautionary approach dictates a risk-averse strategy, in which no fish stock is exploited at a rate higher than one that generates maximum yield, and no spawning stock is reduced to low levels, at which recruitment impairment occurs. In the absence of pertinent knowledge to the contrary, a S/R relationship should be assumed to exist, even for eel. The existing trends in eel landings and recruitment indices support this view, although the exact form of the S/R relationship has not been possible to determine so far.

Recruitment of European eel has been in decline since the early 1980s, and is below 5% of the historical level, since 2000. Total landings have revealed a gradual decline since the 1960s, down to approx. 25% of the former level (Dekker, 2003). The causes of the decline in recruitment are not well known, but might well be related to a low spawning stock. Given the continuously declining trend, data suggest that the present equilibrium point corresponds to extinction or very close to extinction. The ecology of eels makes it difficult to demonstrate a stock–recruitment relationship. However, the precautionary approach requires that such a relationship should be assumed to exist. Therefore, ICES (1999) advised to restrict fisheries and other anthropogenic impacts to the lowest level possible, in order to ensure that the spawning stock returns to then remains above the critical level $B_{lim}$, above which recruitment is not impaired by the size of the spawning stock. Classical fishery management set the critical spawning-stock biomass level ($B_{lim}$) at 30% of that in absence of fishery. Due to the fundamentally different biology of the eel (semelparous with high longevity, panmictic and scattered over the whole continent), the WGEEL suggested a higher $B_{lim}$ of 50% for eels, and EU Regulation opted for a 40% objective.

As an alternative strategy to setting SSB target at an uncertain (30, 40 or 50%?) percentage of the notional pristine SSB (which is not easily estimated), with an unknown corresponding level of recruitment, another approach might be the following: In the 1970s, recruitment of glass eel was still at historically high levels. This indicates that SSB was not limiting the production of recruits at that time. Quantification of the pre-1980 spawner escapement therefore is the simplest derivation of a reference level. Note that in this case, the full escapement (100%) of the silver eels in the 1970s (given the anthropogenic mortality of that time) then is assumed to correspond to the escapement level advised by ICES (2002). That is, one could either set this interim reference threshold at 100% pre-1980 silver eel escapement where the data are available, or in the absence of data, at a percentage of the notional pristine state.

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[1] United Nations Convention on Law of the Sea (1982).

UN Conference on Environment and Development (Rio de Janeiro, 1992).

FAO, Code of Conduct for Responsible Fisheries (1995).

## 4.2 Targets

In general it can be expected that achieving the target defined by the European Council (council regulation No 1100/2007) through management actions will take a very long time. Åström and Dekker, 2007 estimated the time to full recovery of recruitment (the ultimate goal of the management of the eel) to be at least 80 years, if all eel fisheries were closed and none of the other mortality issues addressed. The long-term target defined by the EC then becomes hard to apply in practical management terms. So, for practical reasons short-term, management unit based, interim targets (here called interim targets) need to be defined in connection with management measures to be taken (Figure 4.2).

These interim targets need then to be translated into sub-targets for action on the local scale, which can range in geographical scale from a point source such as a hydropower plant or fishery to the catchment or the scale of the Eel management Unit. This is required as the efficiency of management action has to be evaluated in a short term compatible with the time-scale of the responsible managers and this is shorter than the expected time span for the recovery of the eel stock. Therefore short-term, sub-targets are needed to optimize regional management according to the long-term objective of full stock recovery (Figure 4.2). The sub-targets will be split into management sub-targets directly linked to the set-up of management and into eel sub-targets aiming at increasing the production of eel on a local or regional scale. Management sub-targets may be defined as the number or magnitude of actions taken, i.e. number of dams with passes installed, reduction of fishing mortality, number of habitats and amount of eel stocked. In contrast an eel sub-target could, as an example, be related to the abundance or density for 0+ eel in predefined sections of a catchment.

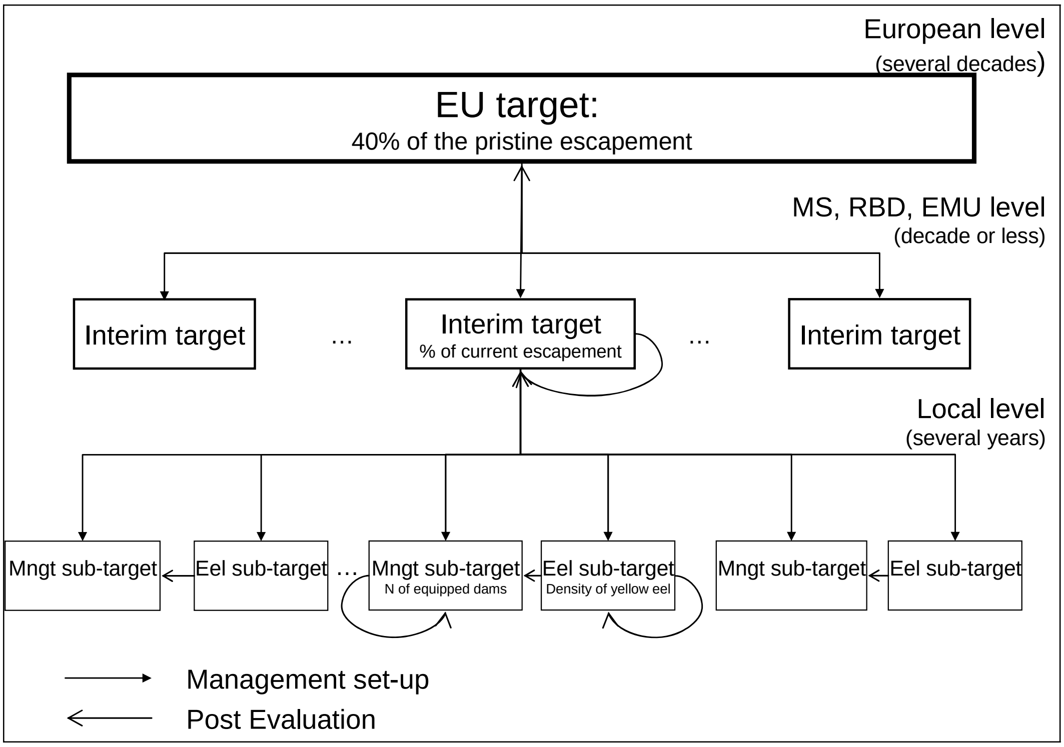


**Figure 4.2: Schematic representation of different targets, interim targets and eel and management sub-targets.**

Both types of target (eel life stage sub-target; management sub-target) should be possible to post-evaluate, i.e. it should be possible to empirically measure the outcome of the management effort relatively soon after it has been applied, and member states are required to collect relevant data to achieve this. For each type of management measures different time-scales for the response in the relevant eel life stage can be expected.

A link between the outcome of the post-evaluation and future management restrictions should be established. In principle, one could use a qualitative link; i.e. whenever the spawner production is below the sub-target, the managers increase their restrictions. However, a quantitative link is preferable, if not a prerequisite as the EC target is defined in quantitative terms; i.e. the post-evaluation method should indicate what level of restrictions is required to achieve the sub target.

The level of the interim and sub targets should be defined so that the long-term target defined by the council regulation No 1100/2007 ("… reduce anthropogenic mortalities so as to permit with high probability the escapement to the sea of at least 40% of the silver eel biomass relative to the best estimate of escapement that would have existed if no anthropogenic influences had impacted the stock. "), (or other relevant, stricter, targets), has a high probability of being reached, in reasonable time. The expected differences in time until different measures result in increased spawner escapement have to be considered in this context.

If reaching the long-term target is not possible, based on the current eel stock within an Eel Management Unit (EMU), and the time schedule for the attainment of the target level of escapement cannot be calculated (although such a time schedule is required by the council regulation No 1100/2007), managers might consider using a stepwise approach with increasingly more ambitious interim targets in sequence over time. This could mean starting out with interim targets and short-term measures based on currently achievable improvements in the eel stock, given the current low recruitment (e.g. a high % of current possible escapement) then moving to an interim target related to escapement of pre-1980 (e.g. 40% of possible (without anthropogenic impact) escapement of the pre-1980), then increasing the required percentage of pre-1980 escapement (e.g. 100% of escapement pre-1980) to finally be able to aim directly for 40% of pristine escapement.

It will need to be remembered that when calculating expected spawner escapement from each RBD/EMU, in response to management measures, it must be emphasized to consider information on the recent recruitment decline, which in most cases will impose a decreasing local stock of eels in the near future, and consequently a declining spawner escapement, which need to be counteracted by the level of the management measures. This also raise the risk of getting a situation where an escapement target might be reached one year, just to drop below the next year being in the risk of a continued decline despite the management measures taken.

## 4.3 Estimation of spawner escapement

The Regulation suggests three options for determining the target level of escapement (Article 2.5):

(a) using data collected in the most appropriate period prior to 1980 to estimate silver eel escapement, provided these are available in sufficient quantity and quality;

(b) a habitat-based assessment of potential eel production, in the absence of anthropogenic mortality factors;

(c) extrapolating with reference to the ecology and hydrography of similar river systems.

### 4.3.1 Estimation of silver eel escapement pre- and post-1980

The definition of silver eel needs to be standardized for escapement estimates. The difference between silvering and silver eels has to be clear and the adoption of the same criteria all over Europe is therefore required. These distinctions have been made clear by some authors (e.g. Acou *et al.*, 2005; Durif *et al.*, 2005) and following them we propose three criteria, which include eye diameter, state of lateral line (presence of black corpuscles) and body colour contrast. It is essential that a standardized method of silver eel identification is adopted for escapement studies.

Estimations of silver eel escapement are available from a number of studies; these are summaries in Tables 4.1a and b for assessments pre and post 1980, respectively. The geographical distribution of the studies data are shown in Figure 4.3. Silver eel escapement is defined as the total number or weight of silver eel that left the catchment, expressed per unit wetted area available to eel for comparison between catchments. Potential silver eel escapement is defined as the number, or weight, of silver eel that would leave the catchment, without anthropogenic mortality, and for Tables 4.1a and b, this has been calculated as the sum of silver eel escapement and the catches of silver and yellow eel and any mortality from other causes (hydropower, illegal fishing, etc).

**Pre-1980** data are available from 25 locations (Table 4.1a). For river systems where lakes are a small proportion of the available habitat for eel production estimates ranged from 1.9–49 kg/ha (n=4). For catchments where there is a sizeable lake component to the overall wetted area (>50%) the estimates ranged from 0.3–17.4 kg/ha (n=4). For lakes, with the exception of the Ijsselmeer where production was estimated at 40 kg/ha only minimum estimates based on silver eel yields from fisheries suggest a range of 0.1–11.7 kg/ha (n=14). For marsh type habitat there is a minimum estimate of 43.7 kg/ha and for lagoons one estimate of 20 kg/ha.

**Post-1980**, the number of assessments of production has increased, but remains dominated by lake studies from Sweden; 66% of the 50 studies (Table 4.1b). Estimates of potential silver eel escapement for rivers varied from 2.7–16.4 kg/ha (n=3), for lake dominated catchments from 0.2–6.4 kg/ha (n=4) and for lakes from a minimum (based on silver eel yield) of 0.04–4.4 kg/ha (n=35). Of the 35 lake studies, two the Shannon and Ijsselmeer provide an estimate of potential silver eel production of 2.7 and 4.4 kg/ha, respectively. There are three lagoon studies with estimates ranging from 6.2–30 kg/ha.

**Table 4.1a: Estimated silver eel yield and production (in kg/ha wetted area), pre-1980.**

| Years | Country | River | Lat. | Long. | Catchment surface area | wetted area available to eel | Waterbody type | Trophic status (mg P per l) | Catchment geology | Stocked | Silver eel yield (kg/ha) | Potential spawner escapement (kg/ha) | Method of calculation of potential spawner escapement | Reference or contact |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | minimum estimate | Håkan Wickström |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | minimum estimate | Håkan Wickström |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | minimum estimate | Håkan Wickström |
| 1975-1987 | Norway | Imsa | 58.9 | 5.9 | 17500 | 1.67 | Lake/River | [illegible] | Siliceous | No | | [illegible] | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | 0.06? | | Yes | [illegible] | | minimum estimate | Håkan Wickström |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | minimum estimate | Håkan Wickström |
| [illegible] | Sweden | Ånger | 60.0 | 17.3 | | 342 | Lake | 0.093 | | Yes | 0.40 | | minimum estimate | Håkan Wickström |
| [illegible] | Sweden | [illegible] | 59.7 | 6.0 | | 7390 | Lake | 0.033 | | Yes | 0.00 | | minimum estimate | Håkan Wickström |
| [illegible] | Sweden | [illegible] | 59.7 | 14.0 | | 1310 | Lake | 0.073 | | Yes | 3.40 | | minimum estimate | Håkan Wickström |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | minimum estimate | Håkan Wickström |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | minimum estimate | Håkan Wickström |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | minimum estimate | Håkan Wickström |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | River | [illegible] | [illegible] | no | | [illegible] | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | minimum estimate | Håkan Wickström |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | minimum estimate | Håkan Wickström |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | 205 | Lake | [illegible] | | Yes | [illegible] | | minimum estimate | Håkan Wickström |
| [illegible] | UK Northern Ireland | Bann | [illegible] | [illegible] | [illegible] | 10 000 | Lake with river [illegible] | Eutrophic | Siliceous | Yes | [illegible] | [illegible] | [illegible] | Derek Evans/Robert Rosell |
| 1981 | Denmark | [illegible] | 56.0 | [illegible] | 12500 | 36 | River | Meso - Eutrophic | Sandy/muddy | No | 19.7 | [illegible] | Mark recapture | [illegible] 1982 |
| [illegible] | Ireland | Erne | 54.5 | [illegible] | [illegible] | 33 000 | Lake/river | Eutrophic | Calcareous | no | [illegible] | 1.3 | [illegible] | Derek Evans/Robert Rosell |
| [illegible] | England | [illegible] | [illegible] | -3 | [illegible] | [illegible] | Lake/river | Oligotrophic | Siliceous | No | | 0.3 | [illegible] (minimum estimate) | [illegible] |
| [illegible] | Germany | Elbe | 53.0 | [illegible] | [illegible] | [illegible] | River | | | Yes | | 5.1 | Model estimate | [illegible] |
| [illegible] | Ireland | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | Lake/river | Oligotrophic | Siliceous | No | | [illegible] | [illegible] | [illegible] |
| [illegible] | Netherlands | [illegible] | [illegible] | 5.4 | | [illegible] | Lake | [illegible] | [illegible] | No | [illegible] | 40.0 | [illegible] | [illegible] |
| [illegible] | Netherlands | [illegible] | [illegible] | [illegible] | | | [illegible] | | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] |
| [illegible] | Netherlands | [illegible] | [illegible] | [illegible] | | | Lake | | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] |
| [illegible] | France | [illegible] | [illegible] | [illegible] | [illegible] | | marshes | | | | [illegible] | | minimum estimate | [illegible] |
| [illegible] | Italy | [illegible] | 44.6 | [illegible] | [illegible] | | Lagoon | | | | | 20.0 | [illegible] | [illegible] |

**Table 4.1b: Estimated silver eel yield and production (in kg/ha wetted area), post-1980.**

| Years | Country | River | Lat. | Long. | Catchment surface area | wetted area available to eel | Waterbody type | Trophic status (mg P per l) | Catchment geology | Stocked | Silver eel yield (kg/ha) | Potential spawner escapement (kg/ha) | Method of calculation of potential spawner escapement | Reference or contact |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | 1766 | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | 79 | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | 884 | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | River | [illegible] | [illegible] | No | | [illegible] | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | 70 | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | 340 | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Latvia | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] | [illegible] | [illegible] | No | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | 600 | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Latvia | [illegible] | [illegible] | [illegible] | | 3797 | [illegible] | [illegible] | [illegible] | No | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | 5017 | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | 590 | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | 70 | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | Sweden | [illegible] | [illegible] | [illegible] | | 205 | Lake | [illegible] | | Yes | [illegible] | | [illegible] | [illegible] |
| [illegible] | [illegible] | Bann | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | Eutrophic | Siliceous | Yes | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | Ireland | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | No | [illegible] | | [illegible] | [illegible] |
| [illegible] | England | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | Siliceous | No | | [illegible] | [illegible] | [illegible] |
| [illegible] | England | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | Siliceous | No | | [illegible] | [illegible] | [illegible] |
| [illegible] | Germany | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | River | | | Yes | | [illegible] | [illegible] | [illegible] |
| [illegible] | Ireland | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | Siliceous | No | | [illegible] | [illegible] | [illegible] |
| [illegible] | Ireland | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] | | Calcareous | No | [illegible] | [illegible] | Catch plus escapement [illegible] | [illegible] |
| [illegible] | Ireland | [illegible] | [illegible] | [illegible] | | [illegible] | Lake | [illegible] | Calcareous | [illegible] | | [illegible] | Catch plus escapement | [illegible] |
| [illegible] | Ireland | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] | | | [illegible] | | [illegible] | Catch plus escapement | [illegible] |
| [illegible] | Ireland | Shannon | [illegible] | [illegible] | | [illegible] | [illegible] | | Calcareous | [illegible] | | 2 | Catch plus escapement [illegible] | [illegible] |
| [illegible] | Netherlands | [illegible] | [illegible] | [illegible] | [illegible] | | Lake | | | | | [illegible] | [illegible] | [illegible] |
| [illegible] | France | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | River | [illegible] | | No | | [illegible] | [illegible] | [illegible] |
| [illegible] | France | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | No | | [illegible] | [illegible] | [illegible] |
| [illegible] | France | [illegible] | [illegible] | [illegible] | [illegible] | | River | [illegible] | | No | | [illegible] | [illegible] | [illegible] |
| [illegible] | Italy | [illegible] | [illegible] | [illegible] | [illegible] | | Lagoon | | | | | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | Lagoon | | | | | [illegible] | [illegible] | [illegible] |
| [illegible] | France | [illegible] | [illegible] | [illegible] | | | Lagoon | | Calcareous | No | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | Sardinia, Italy | [illegible] | [illegible] | [illegible] | [illegible] | | Lagoon | | | | | [illegible] | [illegible] | [illegible] |

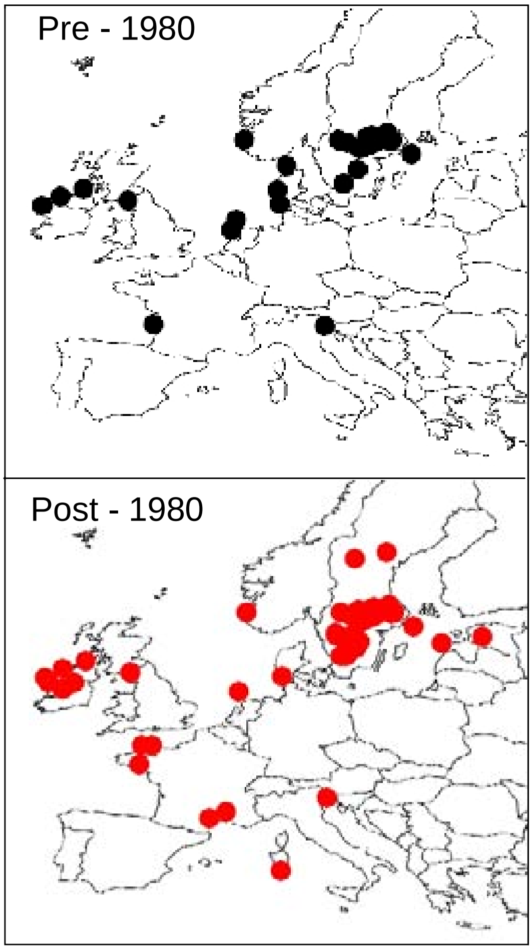


**Figure 4.3: The location of the catchments for which historical (pre-1980 black) and recent silver eel production estimates (post-1980 red) are presented in the Tables above.**

### 4.3.2 Modelling approaches

A number of modelling approaches have been made to estimate escapement or a reference condition to assess compliance with the EU escapement target.

The models are:

- Reference Condition Model (RCM)
- Eel Length Structure Analysis (ELSA)
- Scenario-based Model for Eel Populations (SMEP)
- Global Anguille (GLOBANG)
- Length-based Virtual Population Analysis (LVPA)
- Swedish Analytical Models (SWAM)
- Demographic Model of the Camargue (DEMCAM)
- Glass eel model to assess compliance (GEMAC)

These models and their potential to support the EMPs have been described by EIFAC/ICES WGEEL and Dekker *et al.*, 2006. In addition during the meeting a number of other approaches have been presented to the WGEEL as non peer-reviewed worked examples.

#### 4.3.2.1 Elbe population dynamic model (Oeberst *et al.*, submitted)

An age based model has been developed by Oeberst *et al.*, submitted to examine the population dynamics of eel in the River Elbe (Germany) and estimate the number of eel emigrating from the catchment. The model inputs are quantity of immigrating young eel, number (and weight) of eel stocked, natural mortality and mortality caused by commercial and recreational fishing, cormorants, and hydropower plants. The structure of the model allows the sensitivity of the parameters to the overall estimate to be examined. The model may be used to develop management strategies and to assess the effectiveness of different management options to meet the EU target. It has the advantage of simple adjustment by being modular constructed and can be further developed using MS-EXCEL.

The model assumes that eel remain in fresh water for a maximum of 20 years. The available data for describing the different factors which influence the stock dynamics have different quality. Total catch (kg) per year is estimated for the commercial fishers and angler. The mean weight of the catch (g) and age–length based samples are only available from some areas of the Elbe and short periods. Length based estimates exist for the transformation of yellow eel to silver eel and for the eel which are taken by cormorants based on stomach samples. To combine the different data types a procedure is necessary for transferring length based data into age based data.

For the model it was assumed that eel age >8 were fully recruited to the fishery, this is based on a minimum size limit of 45 cm for commercial and recreational fishers. Recruitment is composed of natural immigration of glass / yellow eel based on monitoring estimates and stocked eel from published reports. Natural mortality is assumed to be constant at 13% (M=0.14) per year (Dekker, 2000). For recreational anglers the total weight of eel caught was the product of the total number of anglers and the mean weight of the catch. The amount of eel consumed by the cormorant population was estimated based on the number of cormorants, their residency time, the daily food intake and the average proportion of eel in their diet (Brämick and Fladung, 2006). The total catch of the commercial and recreational fishers and the consumption of eel by cormorants were converted from a weight based estimate to a number per age using weight to length conversions and a von Bertalanffy growth model. A length based logit-function was used to estimate the proportion of silver eel in the catch of eel by fishers and in the eel consumed by cormorants.

In addition, some general assumptions were used for estimating the catch in number by age group and year because appropriate data are lacking: The age frequency of the catches by fishers and anglers is similar to the age frequency of the stock combined with the requirement that eel younger than eight years are not landed; silver eel are not landed by fishers or the landings can be neglected.

Even though the model is adjusted to the conditions in the river system and to the availability of data, it also includes several assumptions and uncertainties. Therefore, the results of the model will have to be validated by monitoring the stock, especially by silver eel monitoring.

#### 4.3.2.2 Irish model to estimate silver eel escapement (Ó'Néill and Poole, in prep.)

##### Catch based estimates of historic/pristine escapement

The calculation of pristine productivity for exploited catchments requires estimates of silver eel escapement along with historic silver and brown eel catches (Figure 4.4). Historical catch records for silver eel fisheries were available for the five catchments of the Corrib, Moy, Garavogue and Erne. The efficiencies of the fisheries had been previously estimated for the Shannon, Corrib and Erne silver eel fisheries. Where fishery efficiency was not measured an approximately average value of 33% was used to calculate escapement. In addition to the catch at the recording station and escapement past the recording station the brown eel and silver eel catches made upstream were included to estimate pristine productivity. In the absence of historical data for these latter parameters (brown and silver eel catches upstream of the recording station) it was assumed that the yields were equal to those currently observed (2001–2007).

Brown eel yield was assumed to be equivalent to the same weight of potential silver eel. This assumption was based on the logic that in a system subject only to natural mortality, migration would only be delayed such that fecundity (related to weight) would be maximized. Consequently, it is unlikely that there would be a net loss of weight in subsequent years from a cohort. Finally, the productivity estimates were corrected by the level of unreported and illegal fishing. Unreported yield was derived as the ratio of unreported licences to licences issued within the relevant River Basin District between the years 2001–2007. The proportion of the fishery yield taken illegally was assumed to be equal to that estimated for the Shannon by the DEMCAM (SLIME) model (Dekker *et. al.*, 2006). For those catchments with hydropower, an estimate of the impact was derived by imposing a 28.5% mortality per turbine passage (WGEEL, 2002). Therefore, the probability of surviving passage through 'n' number of hydropower installations is $(0.715)^n$.

The estimated pristine spawner escapement ranged from 0.9–5.4 kg/ha with a mean of 3.9 kg/ha (Table 4.2).

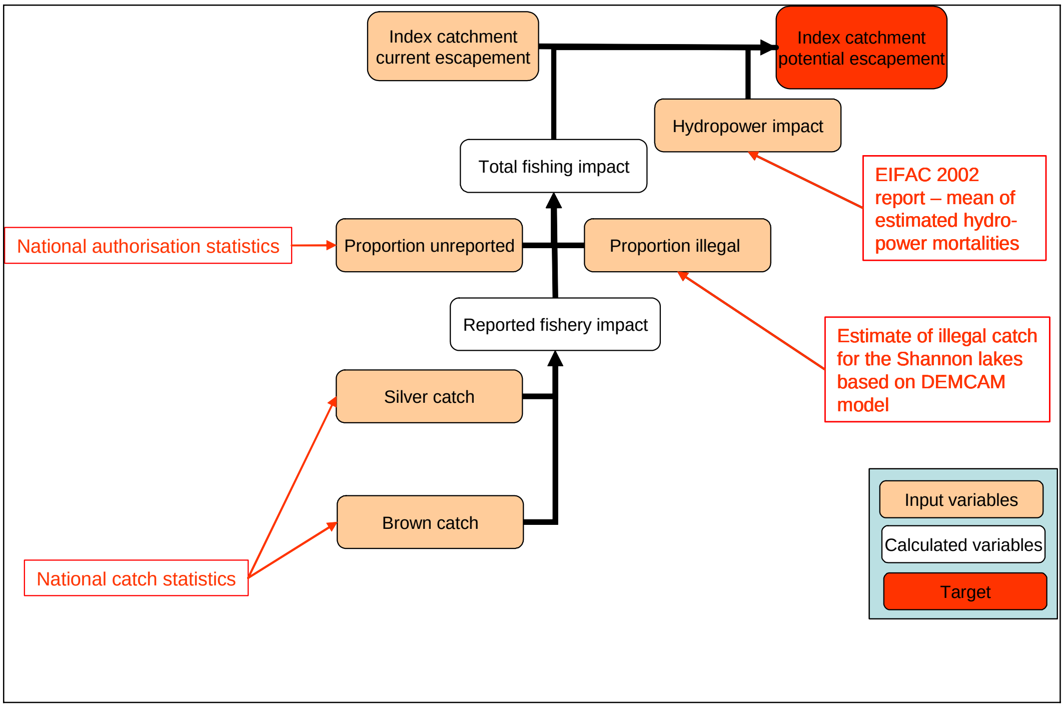


**Figure 4.4: Description of how potential production (escapement) was derived from the current escapement of catchments where estimates of silver eel escapement, fishery yield and the impact of hydropower are available.**

**Table 4.2: Estimated pristine spawner productivity from five Irish catchments based on either direct measurement and/or catch data.**

| | | MOY | GARAVOGUE | ERNE | CORRIB | BURRISHOOLE |
|---|---|---|---|---|---|---|
| | | 1942–1952 | 1962–1975 | 1955–1982 | 1976–1982 | 1971–1980 |
| Silver eel catch at recording station (t) | | 3.4 | 0.9 | 9.2 | 19.4 | 0.0 |
| Escapement past recording station (t) | | 6.8 | 4.4 | 51.3 | 38.8 | 427.5 |
| Brown eel yield upstream (t) | Reported | 4.0 | 1.7 | 13.4 | 9.0 | 0.0 |
| Brown eel yield upstream (t) | Unreported | 3.0 | 1.2 | 23.4 | 6.5 | 0.0 |
| Silver eel yield upstream (t) | Reported | | 0.0 | | 18.6 | 0.0 |
| Silver eel yield upstream | Unreported | 29.1 | 1.2 | 9.2 | 13.4 | 0.0 |
| Hydropower impact (t) | | 0.0 | 0.0 | 25.4* | 0.0 | 0.0 |
| Wetted area (ha) | | 8418.0 | 1783.0 | 25.9 | 28869.0 | 475.0 |
| Productivity (kg/ha) | | 5.3 | 5.4 | 4.5 | 3.4 | 0.9 |

***occurs following recording station.**

### Potential production based on habitats of similar characteristics

The method involved determining the relationship between productivity and the geological characteristics of the catchment.

Growth rate of eel were available for 17 catchments (Moriarty, 1988, Central Fisheries Board). The wetted area within each catchment was quantified using a geographical information system and classified according to the proportion of the catchment area comprising non-calcareous geology. For 17 catchments growth rate was found to be closely negatively related to the proportion of the catchments comprising non-calcareous geology (Figure 4.5) ($r^2=0.67$; $p<0.0001$).

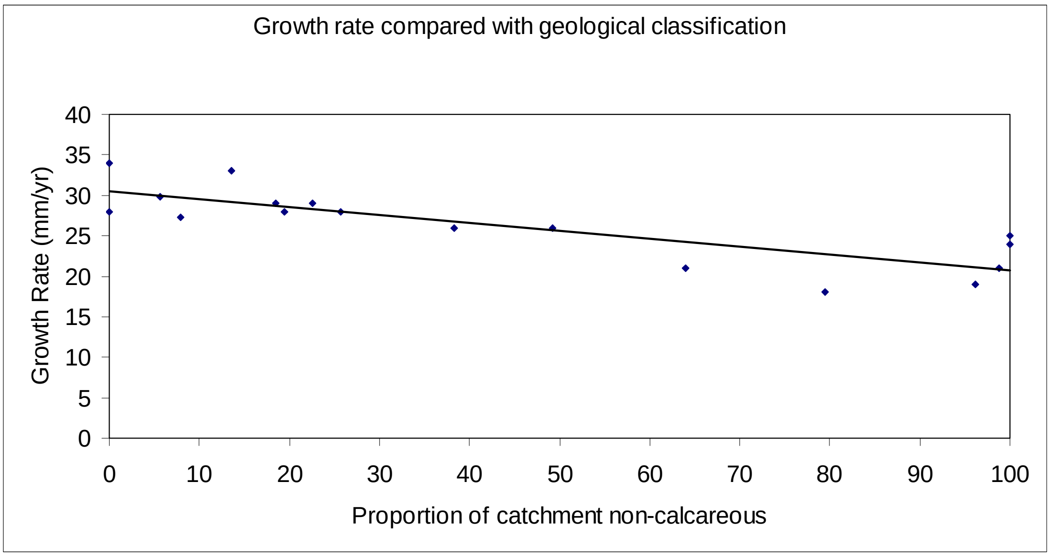


**Figure 4.5: The relationship between growth rate and the proportion of the catchment comprising non-calcareous geology.**

The four catch-based production estimates along with the direct estimate for the Burrishoole (Table 4.2) were plotted against the proportion of non-calcareous geology within the catchment (Figure 4.6). These historic estimates suggest that in exclusively non-calcareous catchments silver eel productivity was approximately 0.9kg/ha whereas in predominantly calcareous catchments silver eel productivity averaged about 4.5kg/ha.

An obvious weakness in the relationship presented in Figure 4.6 is the distribution of the data, with very few data for intermediate or non-calcareous catchments. To increase the robustness of the model the 5 available productivity estimates were used to convert the growth-rate estimates for 17 catchments into pristine production estimates.

Potential silver eel productivity was regarded as a product of recruitment, natural survival and average silver eel weight. Natural mortality was imposed at a constant rate of 14% per annum. This rate was chosen because the average age of Irish silver eels is approximately 18 years and the cumulative natural mortality over the continental life stages is approximately 2.5 (Dekker, 2004). The residence time was the time required for glass eels (70 mm) to grow to the Irish average silver eel length of 480 mm (sexes combined).

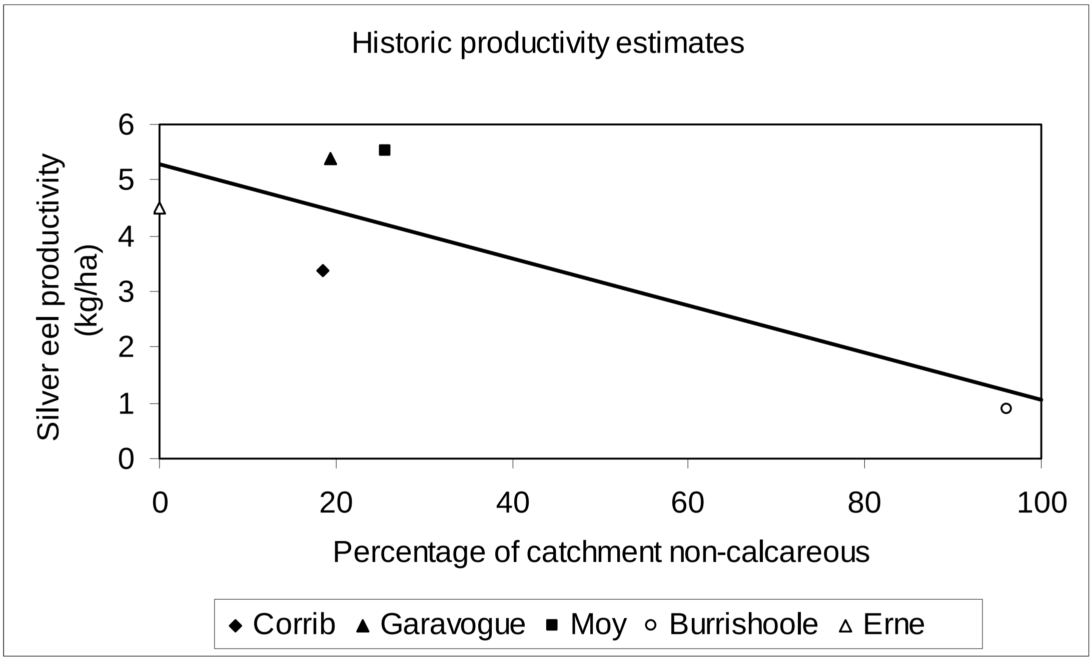


**Figure 4.6: Catch based productivity estimates plotted against the percentage of catchment with siliceous (non-calcareous) geology.**

For each of the 17 catchments the proportion of fish surviving (S) was thus estimated as follows:

$S = (1\text{-}0.14)^{((480\text{-}70)/G)}$

Where G = growth rate (mm/yr)

For those five catchments data on silver eel production was also available (Table 4.2) and these where used as index catchments to estimate potential spawner escapement as follows:

Spawner $\text{production}_x$ = $(\text{Survival}_x/\text{Survival}_i)$ * Spawner $\text{productivity}_i$

Where i= "index" river; x = river where no estimate of spawner production is available.

This calculation was repeated using the survival and spawner productivity for each of the five "index" catchments and the mean computed. The relationship between the estimated productivity and geology for the 17 catchments is shown in Figure 4.7 together with the estimate for those five catchments where productivity had been measured either from catches of by direct measurement.

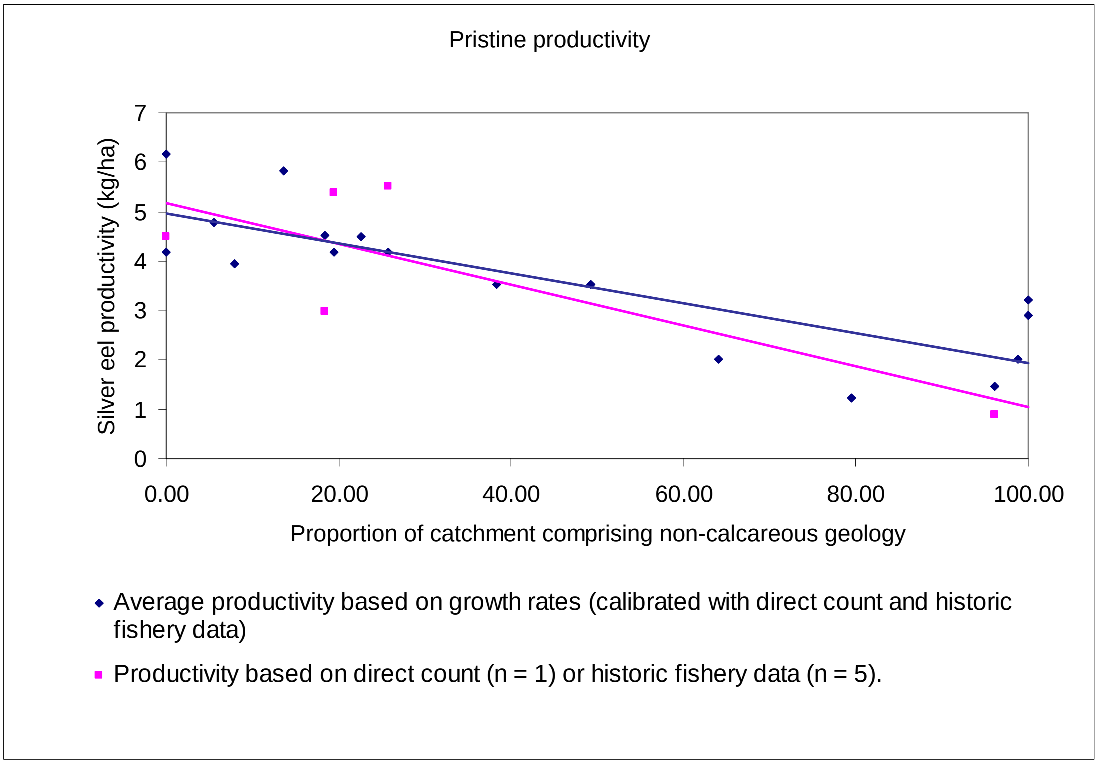


**Figure 4.7: Relationship between silver eel productivity (kg/ha) and percentage of catchment with siliceous (non-calcareous) geology. The pink points are based on catch based or direct estimates of productivity. The blue points are based on the relative productivity of the catch based estimates but these are not included in the regression.**

These data now allow for calculation of pristine productivity (kg/ha) based on either:

1 ) The relationship between silver eel productivity (based on four historic catch records and one historic total count) and the proportion of non-calcareous geology in the catchment using the regression equation:

Productivity (kg/ha) = -0.041*(percentage of catchment non-calcareous) + 5.18

2 ) The relationship between silver eel productivity (based on 17 growth rates calibrated with four historic catch records and one historic total count) and the proportion of non-calcareous geology in the catchment using the regression equation:

Productivity (kg/ha) = -0.030*(percentage of catchment non-calcareous) + 4.97

For Ireland pristine spawner production is estimated at 641 928 kg (4.17 kg/ha) using the regression based on historical catch or total count data and 651 092 kg (4.23 kg/ha) using the regression based on growth rates calibrated with historical catch or total count data.

As reliable data becomes available this approach will be taken to extrapolate from data rich to data poor situations where applicable. This approach is well established for salmon management in Ireland. The regression approach, as described, allows the transfer of data from index catchments with production estimates to catchments where little or no data exists on the basis of geological proxy for production.

#### 4.3.2.3 French methodology to estimate silver eel production (Hoffman, unpublished)

The evaluation of the biomass of silver eel produced in continental waters at the French scale is based on modelling the yellow eel abundance. 20 000 electrofishing operations were used to fit the model. They corresponded to 9000 stations and cover the period 1980–2005. The model describes presence absence and abundance of total densities and densities per class size of 15 cm.

Four categories of variables were used: environment (distance to the sea, temperatures, altitude, geographical area), temporal (month, year), variables linked with anthropogenic pressure (habitat quality, obstacles, glass eel and yellow eel fisheries) and variables associated with electrofishing (fishing method).

The work is based on a GIS database of the French river network, which has been analysed to extract some environmental parameters (distance to the sea, cumulated river length upstream, river width, Strahler rank). Environmental parameters are extracted and densities are predicted in all points of the network. Setting anthropogenic parameters to zero, it is possible to predict the actual pristine productions. Temporal variables allow the prediction of past densities. The combination of both provides a figure of past pristine productions. Densities are converted into numbers by multiplying by the water surfaces.

The aim is to compare the estimated "pristine" 1989 densities with those determined during the 1960s and 1970s and if the latter are higher adjust the pristine 1989 estimate by a factor. This density would then be compared with current estimates (Figure 4.8).

The yellow standing stock will then be compared with actual estimates of silver eel production.

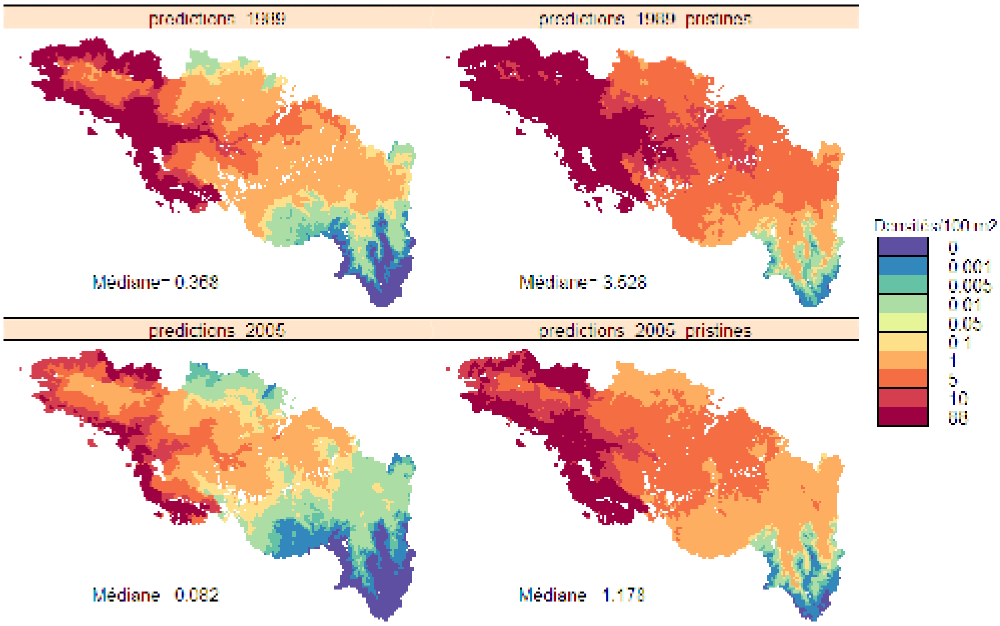


**Figure 4.8: Model prediction in Loire Bretagne of the spatial variation in yellow eel densities (nb/100 m²). Surfaces are not yet calculated so the median of eel densities is shown on each graph. Pristine correspond to predictions without dam and with no glass eel fishery.**

The predicted temporal trend in yellow eel densities estimated at the mouth of the river in the absence of dams for the period 1982–2005 is shown in Figure 4.9. After 1989 there is a steady decline in density. It should be noted that prior to 1989 the method of data collection differed, and the difference may reflect the lower density estimates.

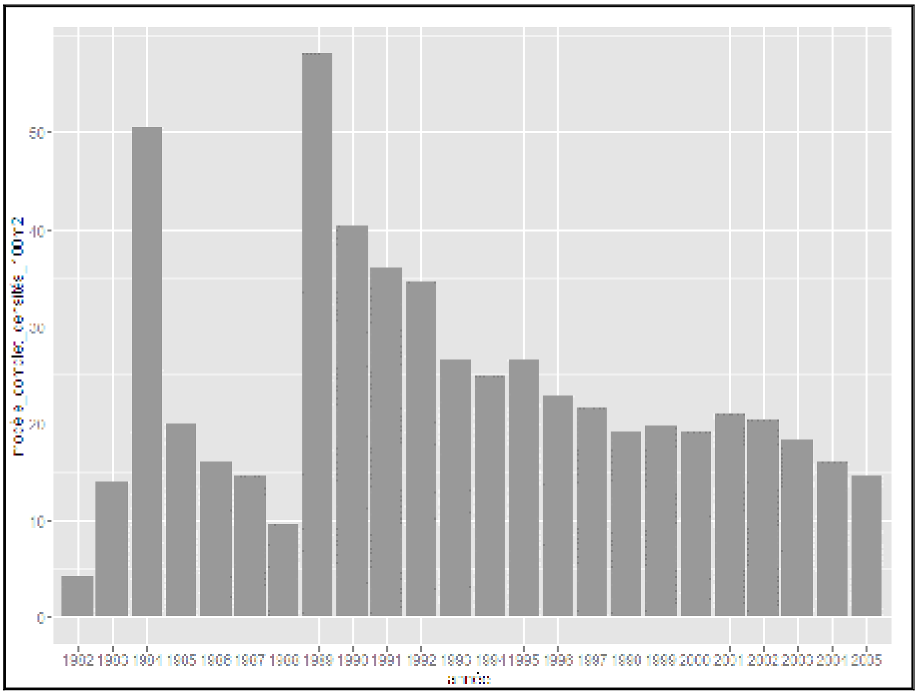


**Figure 4.9: Model prediction of the temporal trend in yellow eel densities (nb/100 m²) in Loire Bretagne. The year effect was classified as category in both presence-absence and abundance when present models, the densities are those predicted at the mouth of the river, in the absence of anthropogenic impact.**

For each obstacle the severity of the obstruction was estimated on a scale of 0–5 and for obstacles in series the impact was estimated to be cumulative. Obstacles have the effect of reducing the density of eel upstream (Figure 4.10). There is a rapid decline in density with an increase in the number and severity of the obstruction falling to approximately a third at a cumulative obstruction score of 50.

The model also predicted that eel density declines with distance from the sea (Figure 4.11).

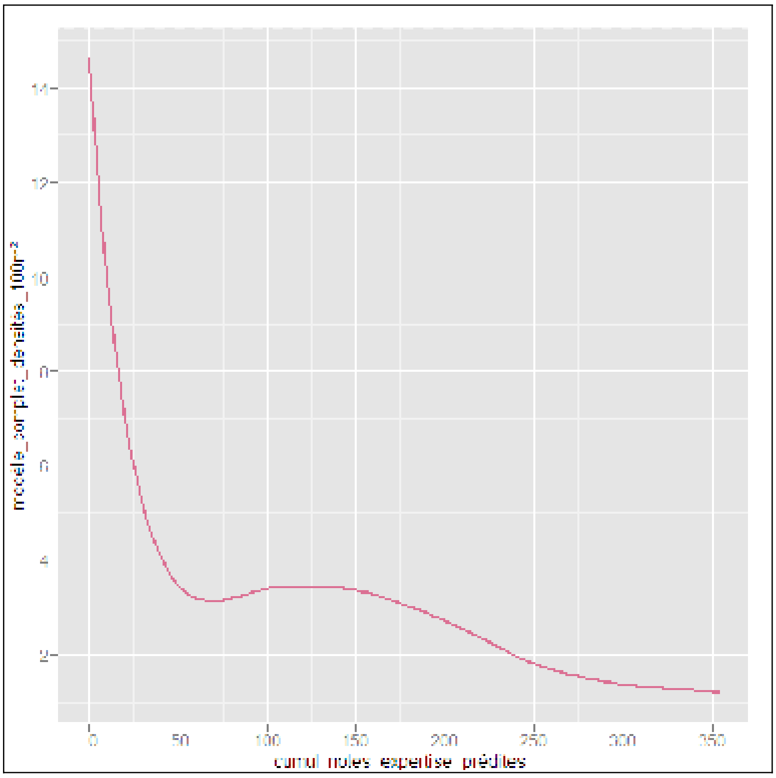


**Figure 4.10: Model prediction in Loire Bretagne of the cumulated effect of obstacles. The effect of obstacles is expressed as a scoring (from 0 to 5 impassable). Densities (nb/100 m²) are predicted at the sea, in 1995, in the Loire, without anthropogenic impact.**

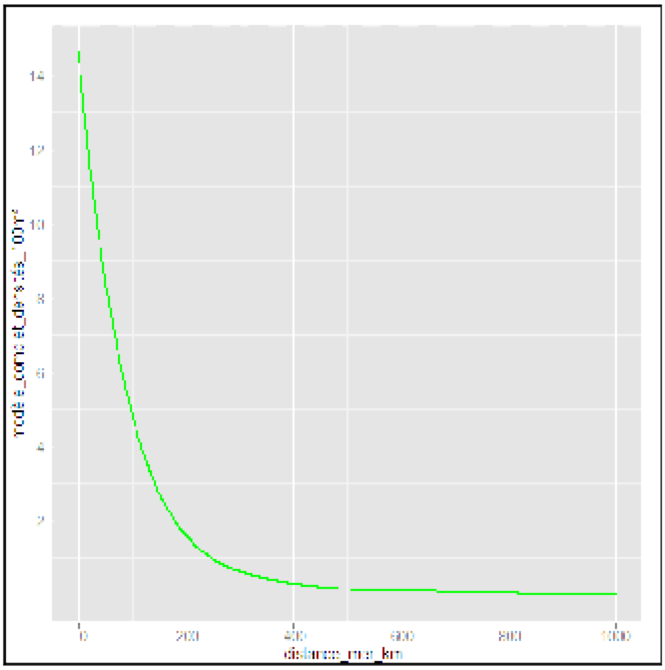


**Figure 4.11: Model prediction in Loire Bretagne of the effect of the distance to the sea. Densities (nb/100 m²) are predicted in 1995, in the Loire, without anthropogenic impact.**

#### 4.3.2.4 Silver eel production in Danish streams (Pedersen, pers.comm.)

Silver eel production in Koge Lellinge stream was estimated to be 105 kg/ha river (wetted area) (Rasmussen and Therkildsen, 1979). The estimate was based on the density of resident yellow eels, observed growth (derived from age reading) and mortality with data collected during the period 1965–1968. The estimate is therefore based on glass eel recruitment during the period the late 1950s and early to mid-1960s. The population consisted mostly of males with mean weight of 100 gramme. The experiment was undertaken in the lowest part of the stream and downstream of a weir, the estimate therefore can not be taken as representative of silver eel escapement for the catchment as a whole but only the lower part of the river.

Silver eel production in River Brede was estimated to be 49 kg/ha river (wetted area) (Nielsen, 1982). The silver eel were caught in autumn 1981 using fykenets with the escapement estimated using mark-recapture and is thus based on the recruitment of glass eel during the period 1965–1975. The population of silver eel was 82% males and 18% females. Average weight was 120 grammes.

Silver eel production in the River Bjornsholm was estimated in 1988 to be in the range 9–39 kg/ha river (wetted area) (Bisgaard and Pedersen, 1990). Densities of resident yellow eel, observed growth rate (derived from age reading) and mortality produced an estimate of 39 kg/ha river (wetted area). This compares with an estimate of 9 kg/ha river (wetted area) from mark-recapture on silver eel carried out in August and September and therefore should be considered a minimum estimate of escapement. Sex ratios of silver eel were 40% males and 60% females with an average weight of 280 grammes.

In Denmark, it is proposed that 50 kg/ha (wetted area) represents “pristine” escapement for the fresh-water environment. This translates into the EU escapement target of 20 kg/ha (wetted area).

#### 4.3.2.5 Quebec approach (Verreault and Lambert, pers. comm.)

A Canada-France-Québec research project was set up to evaluate impacts of barriers opening in terms of escapement and net productivity gain in the fresh-water habitats of the St. Lawrence watershed. This GIS decision tool will be based on eel habitat surface and eel distribution in a watershed. More precisely, the model is based on the exponential decrease of potential yellow eel abundance with distance from marine waters. Then the potential yellow eel density for every river stretch is modulated by the cumulative mortality and passiblity of downstream barriers then converted in absolute abundance of silver eel escaping the system. The model final output will be an estimate of potential production of oocytes by using a size-fecundity relationship.

## 4.4 Future methods for silver eel escapement (yellow eel proxies)

It is essential to adopt standardized methods to estimate escapement, potential biomass (*e.g.* biomass available in the river system) and also effective biomass (that will escape and that has reasonable probability to reproduce) derived from silver eel quality and mortality within the river catchment. Possible methodologies are outlined below and in the INDICANG methodological guide (Adam *et al.*, in press) not yet seen by the WGEEL.

Silver eels biomass production is a primary management target to be urgently achieved for starting the restoration of the European eel (*Anguilla anguilla*) population. An assessment of the proportion of individuals actually escaping from catchments-and able to reproduce-compared to a theoretical pristine production under no human intervention, is of critical importance for preserving this resource, and the EU obliges Member States to implement measures. However, there is currently very little information on silver eel escapement and even less information on silver eel quality (e.g. defined by parasite burdens, metallic and organic contamination of tissues, fat content). In order to estimate effective breeding biomass in data-poor catchments, research is required to develop and implement methods and protocols describing reliable proxies. Such research has recently started during the EU programme INDICANG that proposes to clarify some of the basic concepts needed to implement assessment tools for a characterization of the production of spawning biomass in a catchment. These concepts rely mostly on the influence of the catchment context (conditions for the eel growth) on the silver eel population characteristics (biomass and numbers, sex ratio, size and age structure, condition indices) before migration. The effective breeding biomass (escapement of high quality future spawners) is then estimated by attributing anthropogenic mortality rates (fisheries, hydroelectric turbines, dams and reservoirs). Risk analysis is also needed to define the proportion of eels that are healthy enough (low parasite burdens, high condition and fat content as well as low chemical contamination levels) for successful migration and to contribute to the gene pool. As a first step, this effective breeding potential should be estimated at the catchment area level from the sources to the sea. Then, regional approaches need to be developed and implemented to model relations between catchment characteristics and silver eel population characteristics (Acou *et al.*, in press).

Here we review different approaches which have been implemented or proposed to estimate silver eel escapement. The methods will soon be available and translated in four languages (French, English, Castillano, Portuguese) in Chapters 8 and 9 of a "Guide book for European eel monitoring" produced from INDICANG project (website references). Parts of the results are also presented in Robinet *et al.*, 2008. In addition to being able to quantify the status of the stock information is also needed on processes, particularly growth and mortality, as such there is a requirement to ensure standardization of the method(s) used to estimate age.

### 4.4.1 At the catchment level

#### 4.4.1.1 Estimating silver eel biomass escapement

**Direct estimates intercepting silver eel runs**

a. Commercial silver eel fisheries can, depending on their location and scale, provide good opportunities for direct estimation of the numbers and biomass of silver eels escaping from hydrosystems, by analyses of annual variation in either yield or cpue provided that it is possible to determine the efficiency (proportion of run captured) of the eel capture systems involved. Examples of such investigations, of population dynamics and seasonal patterns of seaward migrating eels, include those undertaken on the River Loire, River Shannon and Corrib, River Bann (Lough Neagh outlet), the River Imsa, the Baltic basin and the St Lawrence. Difficulties can occur when the fishing season does not cover the full migration period or when there is significant eel production downstream of the fishery area. Use of mark/ recapture methods for estimation of fishery capture efficiency allows for estimation of the numbers and biomass of migrating eels at the fishing sites. This can involve use of a variety of tags and marks (see Concerted Action for Tagging of Fish: www.hafro.is/catag). Experimental fisheries could be established in data poor areas and used to improve fishery monitoring methodologies. (Vollestad and Jonsson, 1988; Caron *et al*., 2000; Feunteun *et al*., 2000; Feunteun *et al*., in press; Allen *et al*., 2006; WGEEL Baltic sea; and McCarthy *et al*., 2008).

b. Wolf traps, or related systems, or use of winged nets deployed for research purposes can provide precise estimates of migrating eel population dynamics and under some circumstances all silver eels can be counted and weighed. However, this is usually only possible in smaller river systems where discharge patterns allow for silver eel trapping throughout the migration season. Examples of this type of silver eel escapement estimation include the studies undertaken on the Norwegian River Imsa (Vollestad and Jonsson, 1988), the French Rivers Frémur (Feunteun *et al*., 2000) and Oir (Acou *et al*., in press), the Burrishoole (Poole *et al*., 1990; 1994) and the outlet of Lough Ennel in the River Shannon, Ireland (McCarthy, unpublished data).

c. Counters and various acoustic technologies can allow for the estimation of silver eel escapement in locations where eel capture is not possible. For example, hydroacoustic methods, such as were used by McCarthy *et al*., 2008 to investigate variations in numbers of silver eels migrating downstream in the headrace canal of the Ardnacrusha hydropower plant in the River Shannon, and resistivity counters and Didson acoustic cameras trialled for counting emigrating silver eel in the UK (M.A. Aprahamian, pers. comm.). Such eel counts, and linked data on size frequencies of the migrating eels, are only possible in locations where other fish species (with target strengths in the same range as the silver eels) are not also migrating downstream at the same time as eels. Work is in progress in Ireland, UK, Poland and other European countries that should lead to improved sampling protocols and to more widespread use of this method for estimation of eel escapement rates.

#### Indirect estimates using yellow eel proxies

In many water basins, lack of data concerning silver eel estimates, requires the use of alternative approaches to meet the demands of Council Regulation 1100/2007 for estimating silver eel escapement. The use of proxy indicators from sedentary eels and habitat population models seem to be the most promising approaches (Feunteun *et al*., 2000; Aprahamian *et al*., 2007; Lobon-Cervia and Iglesias, 2008; Feunteun *et al*., in press,). These procedures should nevertheless be standardized so that methodologies used can provide representative estimates of silver eel production, e.g. sampling at the beginning of the migratory season (late summer in southern latitudes and middle summer in northern latitudes).

Mark-recapture or other more locally adequate methods could be used to estimate density of yellow and silver eels. Several habitat types representative of each catchment should be evaluated in order to be able to extrapolate for the whole catchment and include it in habitat population models.

Eel mortality rates need to be determined throughout the river basin including the estuary as well as fresh-water habitat (see also Chapter 3).

In some countries, lack of data on both yellow and silver eels requires a different approach in which, habitat data collected within the WFD should be used in conjunction with eel population data from similar regional areas. However, EMPs based on this provisional approach should also include details of sampling programmes to provide a basis for future determination of spawner escapement.

#### Estimating effective silver eel biomass escapement

Effective silver eel biomass {proportion of the potential silver eel biomass * mortality (Fishery, Hydropower, Natural) * quality} estimation is essential if the actual contribution made by particular rivers, river basin districts or larger scale European regions is to be evaluated now and during post evaluation of EMPs. This integration of data on population dynamics and eel quality has not been subject to the detailed level of discussion to which other elements of the EU eel recovery plan have been subjected. However, a more standardized approach to this topic is required if results of ongoing studies on contaminants, parasites and diseases of silver eels are to be integrated at a European level.

#### 4.4.1.2 Quality

Monitoring quality of silver eels should aim to establish the proportion of migrating eels that have sufficient quality to reach the spawning grounds, breed and produce adequate numbers of viable larvae. In analyses of silver eel populations the extent of quality monitoring will be more limited for eels released following capture and measurement. For released eels, the life-history stage determination, and the usual length and weight measurements, must be recorded for representative subsamples.

Observations of significant decreases in fat levels in yellow eels over 15 years in Belgium and the Netherlands raises serious concerns about their reproductive potential (Belpaire *et al.*, in press), and warrant the inclusion of eel quality estimates within the quantitative targets for escapement.

Considerably more parameters should be requested on a subsample of silver eels. These can involve data on contamination levels of metals and organic (for methods refer to quality section), fat content and condition factor, otolith age reading, *A. crassus* and EVEX and other viral diseases. Information on life-history traits and population characteristics should also be provided for sampled silver eel populations and this can involve sex ratio estimated from size frequencies (with calibration using sacrificed eels). There is a need to establish a size-age relationship and also an index relating eel quality to breeding success.

### 4.4.2 At the regional level

It is anticipated that the EMPs are developed under the River Basin District (RBD) level. The success of EMPs depends on a good coordination and consistency between measures taken under Regulation 1100/2007 and European Directives having impact in the river basin. Therefore, to make EMPs more effective, it is desirable that catchment based models are also developed at a regional level (involving each RBD), aiming at predicting silver eel escapement.

## 4.5 Methods for evaluation of management measures

A close link between both management and eel sub-target will be established in the following sections with regard to selected management measures (Table 4.3). The relationship between management and eel sub-targets will allow for a direct feedback to management if measures are not achieved and/or the locally targeted eel population responded, or failed to respond, in the predicted manner (e.g. an increase in yellow eel density). The methods to evaluate management measures and the response of the targeted eel life stages should be applied locally and therefore give a feedback to the authorities in the eel management units. By this feedback loop local managers will be able to adapt their management approach without regard to the delayed response of the whole eel stock (e.g. changes in recruitment). However the proposed management- and eel-targets are not intended to be an exhaustive list of all possible management measures. It should be taken as a first step in filling the gap between local management and the long-term recovery.

It is also recognized that methods for evaluating the outcome of management measures on the population level (eel sub-targets) are not always fully available and need further research. The same holds true for the definition of different quantitative levels of eel sub-target. The levels have to be related to the actual status of the eel population with respect to the global objective of full recovery (e.g. 40% of spawner escapement without anthropogenic impact). The level of the management action finally depends on how far a certain management unit is away from the objective (refer to Figure 4.2).

### 4.5.1 Management measures and methods for evaluation

#### 4.5.1.1 Commercial fishery

EMP´s will involve fisheries regulation measures throughout the distributional area and across all continental life stages. A range of different measures can be identified and applied to the different life stages. Evaluating the effects may require different approaches and time frames.

<u>Management sub-target 1.1: Effort restrictions.</u> For all life stages, the regulation and limitation of the access to the fishery is a common measure that can be applied.

#### 4.5.1.2 Glass eel fishery

Quotas and partial or total closure of fishing activities are the most plausible methods in managing a glass eel fishery.

<u>Management sub-target 1.1; Achievement of Quota</u>. A defined proportion of the recruits to a management unit is excluded from the local fishery. Evaluation should be based on knowledge of variation in abundance/catchability over time in the season and monitoring of landed quantities.

<u>Management sub-target 1.2; Total or part time closure.</u> A given degree of closure results in a predetermined reduction of fishery mortality. This target must be based on the knowledge of glass eel abundance over time in the fishing area and may be monitored by field control of fishing activities.

#### 4.5.1.3 Yellow eel fishery

Quota, total or part time closure, size limits and closed areas are measures applicable in regulating most fisheries, including fishing for yellow eel. Technical regulations of the fishery for yellow eel may have different effects depending on where they are imposed in a catchment. If they are imposed downstream, in an estuary or near the area of primary recruitment, they may have an effect on density-dependent migration and thus proliferate upstream in the river basin. On the other hand, if they are introduced upstream in a system, where the subpopulation has a higher degree of residence, the expected effect will primarily concern demography and mortality. The statements above suggest different designs of monitoring and short-term evaluation.

<u>Management sub-target 1.3; Quota.</u> A defined proportion of the yellow eel stock in a management unit is excluded from the local fishery. Evaluation should be based on knowledge of the local production in the area and effects of a regulation can be monitored in landed quantities.

<u>Management sub-target 1.4; Total or part time closure.</u> A given degree of closure results in a predetermined reduction of fishing mortality. Evaluation of this target needs stock assessment models, which are often dependent of an existing fishery. A total closure thus is easier to evaluate.

<u>Management sub-target 1.5; Size limits</u>. Imposing size limits is targeting reduction of fishing mortality. Evaluation of this target needs stock assessment models, which are often dependent of an existing fishery.

Management sub-target 1.6; Protected areas. A management target for protected areas could be evaluated as the proportion of the available habitat or productive potential that is taken out of fishery. In this case, as in most other cases, the proper management target is a certain reduction of fishing mortality in the management unit.

#### 4.5.1.4 Silver eel fishery

The most plausible tools to manage a silver eel fishery are total or part time closure and size limits. Protected areas may also be considered.

Management sub-target 1.7; Total or partial closure should fulfil the target to reduce mortality by a predetermined value. Evaluation must be based on a good estimate of the number of eel that would be caught if fishing was open and the total catch in the open season. This target may be monitored using landings and historical information on distribution of catches over the entire season.

Management sub-target 1.8; Legal size limits may include exclusion of the smallest as well as the biggest individuals from the landed part of the catch. This target should be set bearing in mind the total effect on effective SSB. Egg production may not be/is not linearly related to body weight (Verreault, 2002). Compliance with the target must rely on sampling of the size distribution in the total catch, discards included.

Management sub-target 1.9.; Protected areas. The effect of protected areas should target a certain proportion of the silver eel production in a management unit and should be restricted/closed for all types of fishing activity, i.e. $F$=0 for x% of the potential production.

#### 4.5.1.5 Recreational fishing

In parts of Europe recreational fishery generates a major part of the fishing mortality. This kind of fishing is to a great extent focusing on the yellow eel stage but capturing silver eel may also occur (Staas, 2006). The measures available for managing this sector of fishery are primarily the same as those for the commercial fishery. Thus the biological targets are similar to those presented above under yellow eel fishery. All management actions described in the same section could be applied to recreational fishery. The presence of poaching though, may introduce the need for official control.

Management target 1.10.; Control of effort. This target should be the control of effort taken in a management unit or in predefined parts of a management unit.

#### 4.5.1.6 Actions to make rivers passable and enhance habitat quality

##### Upstream migration

Management sub-target 2.1; number of dams where eel ladders will be installed, especially in and near the zone of active colonization:

Management sub-target 2.2; surface area of river channels and lakes in a catchment or a percentage of lost habitats that could become recolonized by eels.

Evaluation of management sub-target 2.1 and 2.2 could be achieved annually by listing of the recently equipped dams combined with GIS techniques of upstream surface measurement.

The conversion of the management targets into an eel sub-target assume that all habitats within a river system are equally productive per unit surface area and eels were totally excluded upstream of man-made obstacles (Verreault *et al.*, 2004; ICES 2007).

Management sub-target 2.3; number of fish passing over the obstacles. To determine these numbers an eel ladder should be equipped with a fish counting device (trap, video camera etc.). However, passage of fish may fluctuate a lot with several peaks during the migration period. For example, in the River Couesnon, 75% of the fish trapped occurred within four weeks whereas 17 weeks contributed to less than 10% of the total catch (Legault, 1994). The target in absolute numbers could be difficult to achieve in the short term especially when a decreasing recruitment trend is observed. It is probably better to define a relative target i.e. percentage of fish that succeed to migrate upstream. Briand *et al.*, 2005a undertook a survey of arrival near the obstacle by using a mark and recapture technique but this kind of application is difficult to execute and repeat for a long period.

#### Downstream migration

Current practice of stocking and the (recent) construction of fish passes have led to the establishment or maintenance of yellow eel population in habitats situated upstream of hydropower plants. In many cases these areas will be included into the natural eel habitat. But when reaching the silver eel stage a fairly large proportion of these eel are lost as a consequence of turbines passages and or impingement. Possible mitigation measures consists of installing bypass systems, switching off hydropower turbines temporarily and capturing downstream migrating silver eels (and incidentally yellow eels) before entering hydropower turbines.

Management sub-target 2.4; number of obstacles where appropriate bypass systems will be installed, or where hydroelectric power turbines should be switched off temporarily, or where trap-and-transport measures will be carried out.

Evaluation of this management target could be achieved annually by listing the recently equipped dams.

### 4.5.1.7 Reduction of environmental contamination

Management sub-target 2.5; reduction of pollutant discharge until total prohibition of use for the most dangerous contaminants.

The direct evaluation of such target is not simple because it is difficult to estimate the quantity of pollutants being input to the river, especially when sources of pollutant are diffuse.

### 4.5.1.8 Increase of habitat quality

Management sub-target 2.6; Wetted surface area of river where eel habitat quality is improved.

As with contaminants the direct evaluation of such a target is not simple because it is difficult to estimate the habitat quality and the relationship with the quantity of eel.

### 4.5.1.9 Stocking of glass eel or pre-grown (farmed) yellow eels

If stocking is to be used as a management measure according to the EU-Regulation, it has to be assumed that stocking is performed at the actual state-of-the-art (decision tree and stocking protocols are available; see Chapter 5) with respect to carrying capacity and sufficient quality of the chosen habitats (see relevant data collected under the WFD). The health status of material used for stocking with special regard to parasites, viruses and other pathogens has to be checked. Additionally silver eels produced from such stockings should be able to escape from the habitats without major losses as a consequence of pumping stations or hydropower turbines.

Management sub-target 3.1 Defined proportion of habitat with low recruitment in the management unit for supplementation of eels and number of eels stocked per surface unit (ha) according to available eel surplus for stocking.

Management sub-target 3.2 Defined proportion of natural eel habitats without recruitment and number of eels stocked per surface unit (ha) according to available eel surplus for stocking.

Stocking activities will in future rely on the assumption that a surplus of glass eel from at least some European estuaries is still available. In view of high prices for glass eel the locally available budget may limit stockings more than biological or logistical aspects.

#### 4.5.1.10 Measures related to aquaculture for stocking

A great proportion of glass eel captured in Europe is currently used for eel production in aquaculture. This proportion is assumed to diminish in the next years as according to the EU-Regulation up to 60% of all eel below 12 cm should be reserved for stocking. On the other hand stocking, as a conservation measure, can include eels up to 20 cm in length. This is in accordance with current stocking practice using pre-grown eels from aquaculture for release in natural eel habitats. As prices of glass eel tended to be high in recent years and glass eel are assumed to face a high natural mortality in the first years this practice will probably continue in coming years. As a consequence of rearing conditions there is a concern about the quality of such eel released after a time in conventional eel aquaculture with regard to health status and genetic diversity (see Chapter 5.4.2.3).

Management sub-target 4.1 Ensure the production of sufficient numbers of eels (for stocking) with a good health status with respect to parasites (*Ang. crassus*), viruses (HVA, Eve, EVEX) and other pathogens.

Management sub-target 4.2 Ensure the production of eels from aquaculture with a minimum genetic selection and avoid stocking of slow growing individuals sorted out from aquaculture.

### 4.5.2 Eel sub-target

#### 4.5.2.1 Glass eel sub-target

Eel sub-target 1.1; Density target for wild (and stocked) 0+ in predefined sections of a catchment.

This can be monitored in ladders and/or by electro-fishing and to be evaluated against historical data. A short-term response is expected (few months).

Time frame for revision management action: 1 year.

*Indicators*; n/ha, absence/presence, front of colonization.

#### 4.5.2.2 Yellow eel sub-target

Eel sub-target: Profile of eel occurrence according to longitudinal position in the catchment. More precisely, this target can be expressed in distance from the sea where the probability of eel presence is 50%.

No information on time-scale of response, probably few years depending on latitude.

*Example of application*

This methodology is based on an analysis electro-fishing data with logistic regressions. Lasne and Laffaille, 2007 estimated that study of temporal trends of "eels' logistic profiles along the longitudinal gradient" allow the assessment of the improvement of colonization after mitigation of local impacts.

Eel sub-target: Density of yellow eel in the upstream reaches.

A short-term target could be set as a specific increase in density on a certain level in a river system after a certain period of time. Compliance can be monitored by mark-recapture, counting in ladders, by electrofishing, with fykenets or other kinds of fishery-independent methods (ICES 2007) and can be evaluated referring to historical data or expected densities from models.

No information on time-scale of response, probably few years depending on latitude.

*Indicators*

Numbers passing, n/ha, cpue.

*Example of application*

An illustrative example is given by the reopening of the Vilaine watershed (Briand *et al.*, 2005b). The construction of the eel ladder resulted in high densities (>1 eels/$m^{-2}$) in the downstream and middle stream areas after two or three years after. These changes remain clear and the examination of five years of data has changed little of the conclusions expressed after only two years. Number of glass eels climbing the fish ladder led to the colonization of the entire basin and a possible saturation in the downstream and middle stream areas. But decrease of glass eel arrival and density-dependant mortality could complicate the interpretation of the results, by inducing a decrease in density in some parts of the catchments (Briand *et al.*, 2005b). A similar approach was performed on the Fremur River and stressed again the importance of maintaining longitudinal connectivity in rivers.

Eel sub-target; Degree of habitat saturation of yellow eel.

Response in distribution/habitat saturation level in the entire catchment can vary in time frames according to latitude, altitude, climate, etc. A reasonable estimate is that a sub-target like this could be set to 3–5 years in the central area of distribution. The target fulfilment can be evaluated against historical data or densities from models.

*Indicators*

Ratio between saturated and unsaturated surface, ration between actual density and carrying capacity.

Eel sub-target: Sex distribution.

An increase in density induced by a reduced fishing mortality may result in a density-dependent change in sex ratios. Evaluation of the appropriate target level will be difficult, but may be based on historical data.

*Example of application*

The Baltic eel stock declined sharply in the 1960s and the 1970s following a preceding decline in recruitment of young yellow eel into the Baltic Sea. The hypothesis was raised that the reduced recruitment was due density-dependent processes in the areas of primary recruitment, i.e. the Kattegatt and the Danish straits (Svärdson, 1976).

Following this male eel almost completely disappeared in SW Sweden. An effect of density on sex ratio was also observed in Lough Neagh in Northern Ireland (Rosell *et al.*, 2005).

The time frame for a response in density-dependent sex differentiation is uncertain, as there is a period of time between recruitment and sexual differentiation.

##### *Indicator*

Proportion of sexes per size group.

Eel sub-target: Short term response in mortality rate.

Local estimate of global mortality (fishing mortality, other source of anthropogenic mortality) rate can inform on pressure on the stock.

##### *Example of application*

The LVPA assessment models quantify the population state and the impact of fishing, for the data years Dekker, 1996 #865}. A minimum of assumptions and a maximum of data ensure a close tracking of the true population state in recent years; in particular, estimates of both the population number and the fishing mortality by length class are updated annually. The Beverton and Holt methodology easily allows for simulation of alternative fishing regimes, and derivation of reference points. Application on the yellow eel fisheries in Lake Ijsselmeer demonstrated that this fishery overexploit the local stock of eel. Current fisheries reduce male spawner escapement to one in seven parts and reduce female spawner escapement to one in seven hundred parts of the unexploited situation (Dekker, 2000).

ELSA is a modelling approach based on eel length taken into account relative change in recruitment, sex ratio, growth, natural and fishing mortality and rate of silvering. It is useful to estimate total mortality rate from a simple length structure above 30 cm (Lambert *et al.*, 2006). The information about eel stock status provided by an application on the Gironde estuary present analysis urges to implement management actions in fresh-water part of the estuary.

##### *Time frame for revision management action*

Two to five years (should be revised).

#### 4.5.2.3 Silver eel sub-target

Eel target: level of mortality rate for each obstacle, maximum delay for migration. For global river management, cumulative mortality and delay can be targeted.

An approximate estimate of turbine mortality can be obtained using empirical formula from literature (Larinier and Travade, 1999). More accurate estimations of eel mortality rates can be obtained by telemetry procedure although they are difficult to obtain as a consequence of the uncertain behaviour of eels during their downstream migration (ICES 2007).

Evaluation of such target should take into account the variability induced by environmental fluctuations and therefore a multi-annual survey is advised.

##### *Time frame for revision management action*

Two or three years.

Eel target: Number of silver eels escaping

This can be monitored by catch statistics, direct counting methods, or mark–recapture experiments (ICES 2007).

The potential production of silver eels can be deduced by converting the re-established yellow eel population or production (data from electro-fishing) into silver eel using simple population models. Where downstream dams are present, escapement estimates should be adjusted to account for cumulative mortality from dam passage.

*Time frame for revision management action*

One to five years.

#### 4.5.2.4 All life stage sub-targets

Eel sub-target 4.1: Level of contaminant load in eel. Measurements in fish are possible for many contaminants, especially for lipophilic ones since eels are particularly sensitive to bioaccumulation of such contaminants. Eel measures give better responses (% of detection) than measurements in water or in sediment (Belpaire and Goemans, 2007a) and an adaptation of the Flemish survey (Belpaire and Goemans, 2007a) to the relevant scale of the studied source of pollution should be advised.

The time response of these management actions depends mainly on the persistence of the contaminant in the field. For example, in Flanders lindane load decreased rapidly after its ban in 2002, whereas DDT continues to slowly decrease 30 years after prohibition (Maes *et al.*, 2008).

Eel sub-target 4.2; Level of quality index. An index of (yellow or silver) eel quality is important for evaluating the net effect of silver eel escapement on reproduction.

Fat content could also be good proxy indicator of the contamination level and a subsequent decrease in yellow eel fat content has been tentatively linked to the capability of silver eels to perform the migration to the Sargasso (Belpaire *et al.*, 2008). Health status of eels used for stocking especially with regard to *A. crassus* and viruses such as HVA, EVE and EVEX can complete this index.

**Table 4.3: Linking management sub-target and eel sub-target. Relation in a short term between management sub-targets (level or magnitude of action in local management) and eel sub-targets (response of the eel population to management) (GE: glass eel YE: yellow eel; SE silver eel).**

| | | | Eel sub-target | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | GE | YE | | | | | SE | | | |
| | | | 1.1; Den sity | 2.1 Occur-rence | 2.2 : Density | 2.3.; Habitat saturation | 2.4. Sex Distri-bution. | 2.5 Mortality rate | 3.1; Obstacle mortality | 3.2 Escapee number | 4.1 Conta-minant load | 4.2; Quality index |
| Management sub-target | Fishery | 1.1 ; GE Quota | ✓ | ✓ | | | | | | | | |
| | | 1.2; GE time closure | ✓ | ✓ | | | | | | | | |
| | | 1.3; YE Quota | | ✓ | ✓ | ✓ | ✓ | ✓ | | | | |
| | | 1.4; YE time closure | | | ✓ | ✓ | ✓ | ✓ | | | | |
| | | 1.5; YE Size limits | | | ✓ | ✓ | ✓ | ✓ | | | | |
| | | 1.6; YE Protected areas | | ✓ | ✓ | ✓ | ✓ | | | | | |
| | | 1.7; SE time closure | | | | | | | | ✓ | | |
| | | 1.8; SE size limits | | | | | | | | ✓ | | |
| | | 1.9. SE protected areas | | | | | | | | ✓ | | |
| | | 1.10. Control effort | | | | | | ✓ | | | | |

**Table 4.3: continued.**

| | | | Eel sub-target | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | GE | YE | | | | | SE | | | |
| | | | 1.1; Den sity | 2.1 Occur-rence | 2.2 : Density | 2.3.; Habitat saturation | 2.4. Sex Distri-bution. | 2.5 Mortality rate | 3.1; Obstacle mortality | 3.2 Escapee number | 4.1 Conta-minant load | 4.2; Quality index |
| | Upstream migration | 2.1; Equipped dam number | | ✓ | ✓ | ✓ | ✓ | | | | | |
| | | 2.2; Opened surface area | | ✓ | ✓ | ✓ | ✓ | | | | | |
| | | 2.3; Fish passing number | | ✓ | ✓ | ✓ | ✓ | | | | | |
| | Down-stream mig. | 2.4 N°. of obstacles | | | | | | | ✓ | ✓ | | |
| | Pollution | 2.5; Pollutant reduction | | | | | | | | ✓ | ✓ | |
| | | 2.6; Improved habitat surface | | | ✓ | ✓ | | | | | | |
| | Stocking | 3.1 Surface of habitat with low recr. and N°. of stocked | | ✓ | ✓ | ✓ | ✓ | | | | | |
| | | 3.2 Surface of habitat without recr. and N°. of stocked | | ✓ | ✓ | ✓ | ✓ | | | | | |
| | Aquaculture | 4.1 N°. of produced eels with a good health status | | | | | | ✓ | | | | ✓ |
| | | 4.2 N°. of produced eels with minimum genetic selection | | | | | | ✓ | | | | ✓ |

## 4.6 Conclusions and recommendations for Chapter 4: Assessing stocks and management actions

### 4.6.1 Conclusions

It is suggested that managers define interim targets for the management measures in order to integrate local action efficiently to the aim of long-term recovery of the European eel stock. For this purpose management sub-targets defining the magnitude of actions (e.g. number of dams removed) will be linked with eel sub-targets reflecting the expected short-term response of the local eel population. Eel sub-targets should therefore allow a fairly rapid evaluation of the management measures taken but sensitivity and time response of some of the proposed eel sub-targets would need further investigation before their application would be operational.

Eel sub-targets should finally be integrated into the evaluation of the status of the whole eel stock. However it has to be recognized that adequate methods or modelling approaches for doing this exercise are still lacking.

Implementation of EMPs requires the development of methodologies to obtain those data. They can include either direct (*e.g.* mark-recapture) or indirect measures (yellow eel proxies to determine silver eel production and eel habitat modelling production). It is important to ensure standardization and quality control of the method(s) used to estimate age.

Use of direct methods, though preferable in many respects, will be severely restricted by: uneven distribution of silver eel fisheries within and between regions; limited fishery monitoring resources; and in extreme fluctuations in large river flows. However, where possible, use of direct methods should be prioritized.

A variety of indirect methods, mostly dependant on yellow eel proxies and modelling, are available for areas where direct measurements of silver eel escapement are not possible and should be extensively used to estimate regional and national silver eel escapement. Selection of models should take account of SLIME conclusions and advice given elsewhere in this report (Dekker *et al.*, 2006). Validation of indirect methodologies should be undertaken on an ongoing basis for a network of river systems where reliable direct estimation of silver eel escapement biomass is possible.

Estimation of effective spawner biomass should be undertaken in all EMPs (*i.e.* at local, regional and national levels) and this will require quantification of adverse effects of contaminants, low fat levels, non-lethal turbine damage, viral diseases, along the lines previously proposed for *A. crassus* as well as other anthropogenic mortality rates along the river catchment. Local management decisions should then be made by reference to effective silver eel escapement rather than total spawner biomass estimates.

There are very few quantitative estimates of pristine (pre-1980) and current silver eel production to allow comparisons to be made between systems and there is very few data on the importance of estuarine and coastal populations to overall production. Modelling will be needed to transfer estimates from data rich to data poor systems. Some approaches have been outlined by this Working Group which complements those from presented in previous working Group reports and in Dekker *et al.*, 2006.

### 4.6.2 Recommendations

- well defined sub targets for short-term, local management efforts should be used, and that data should be collected so that they can be post-evaluated both regarding the fulfilment of the management efforts and the anticipated effects on eel;
- population model(s) should be used to assess the status of stock, compliance with (sub) target(s), to evaluate management actions and to evaluate the influence of biotic and abiotic factors on the stock at a range of geographical scales;
- adaptive feedback links are established between post-evaluation results and resulting changes in management efforts;
- care should be taken so that locally established (short-term) sub targets ensure long-term recovery, eventually leading to the restoration of the spawning stock so that the eel reach full recruitment capacity.;
- since short time evaluation of management actions urges for a list of monitoring activities, fishery dependent as well as fishery-independent, methods for monitoring in connection to the sub targets presented by the WGEEL in this report and in the report of 2007 should be implemented ASAP within the DCR and elsewhere and that where possible these activities should be coordinated nationally with related monitoring activities, i.e. regarding biodiversity within the WFD;
- the concept of effective spawner biomass escapement should be adopted for all EMPs and comprehensive protocols for integration of standardized eel quality data should be developed for application of this concept;
- standardized terminology, and identification criteria be adopted, for use in all European eel programmes;

# 5 Stocking and aquaculture

## 5.1 Introduction

Stocking and transfers of juvenile eel have been discussed at length by the Working Group (most recently ICES, 2006 and 2007). These discussions have covered the principles and extent of stocking, stock transfer practices and their contributions to fisheries. Their effect on escapement has been discussed mainly in conceptual and theoretical frameworks as a consequence of a lack of hard data. The WG 2007 recommended that "guidelines, or best practice manuals, should be established for methodologies for ……. stocking of eel".

**ToR b) develop methodologies for the assessment of the** status of the eel stock, the impact of fisheries and other anthropogenic impacts and of implemented management measures; this might include, for example, support for EMPs on the determination of "pristine" spawner production levels and **relative contribution of stocking.**

Extract from 2006 WGEEL report-the changing scientific advice regarding stocking.

"Scientific advice on re-stocking has changed over the years, from clearly in favour (Moriarty and Dekker, 1997), to against on precautionary grounds (ICES, 2000). In our previous report (ICES, 2005b), the risks involved were discussed, balancing potential genetic effects against the risk that the current stock might suffer from depensatory effects in the reproductive phase, for which re-stocking might be one solution.

Clearly, arguments both pro and contra re-stocking remain valid, and no final and scientific advice can be derived. However, the previous advice was based on the potential for depensation occurring in the reproductive phase. All arguments pro and con being as they are a more practical and nearby argument has come to the fore in this report: that seed stock areas might progressively become depleted as a consequence of a continued decline in glass eel immigration. Options for potentially successful restoration of the stock by glass eel restocking are fading. Re-stocking of glass eel, either in southern areas rapidly contributing to silver eel production, or in northern areas with a long postponed and long lasting contribution to silver eel production, therefore needs urgent consideration."

The Working Group revisited this topic in 2008 in order to provide updates on stocking figures and practical information to support stocking best practice and will provide support to EMP's and the EU Commission.

## 5.2 Methods to assess the relative contribution of stocking to the regeneration of the European stock, and for EMPs

### 5.2.1 Source of glass eel

Advice from ICES to the EU commission (ICES, 2005a) was that the recent glass eel catch (ca. 100 tonnes) is less than that required (150 to 1000 tonnes) to supply the total potential productive habitat (about 40 000 km2), and ACFM further concluded that full-scale restocking alone is unlikely to achieve the EU objectives in the medium term (ICES, 2006).

Therefore, the advice remains that there are likely to be insufficient glass eel available from the fishery to meet the demands for stocking at the European level. However, the Regulation EU: 1100/2007, requires that fisheries make at least 35% of eel <12 cm available for stocking in 2009, rising to 60% by 2013. The implementation of EMPs in 2009 may effect the reduction in some glass eel fishing effort, either as part of local

Management Plans or as a consequence of the 50% cut required where plans are not submitted and approved. This outcome will not be known until the EMPs are published. Here, we consider the potential effect (benefit) of this stocking material.

### 5.2.2 Yield potential

The yield potential can be calculated from Yield/Recruit (Y/R) estimates. Most of the data on Y/R available are obtained from stockings in lakes and an Italian lagoon. The data for lakes range from 5–72 g.stocked eel$^{-1}$, but most are in the range 20–50 g.stocked eel$^{-1}$. The yield-per-recruit in the Italian lagoon appears to be more than twice as high. If the total catch of glass eels in Europe is in the region of 100 tonne (ICES, 2005) of glass eels, with 3000 glass eels per kilo, and 35% (minimum requested by the Eel Regulation) provided in 2009 for stocking, this would have a production potential for approximately 2000–5000 tons of silver eel after one eel generation time. When 60% of the catch becomes available in 2013, it will have a lifetime potential for 3500–8500 tons of silver eels given no anthropogenic mortality. ICES 2006 produced comparable results (10 000 tons of silver eels when stocking 100 tons of glass eels) when using population dynamic calculations and data from Moriarty and Dekker, 1997. The above estimates are maximum estimates, based on the assumption that the catch of glass eel will be in the region of 100 tons. There is of course the possibility that there may be no surplus of glass eels in the near future (ICES, 2007).

Glass eel are caught using moving and stationary fishing gears. There is evidence that handling mortality of some of these gears, e.g. trawls may be up to 40%. Reduction of these mortalities would lead to the more efficient use of the limited and declining resource of glass eels.

## 5.3 Review of stocking activity across Europe

Before the WG meeting, a simple questionnaire was sent to the WG members in order to obtain additional information. The responses to this questionnaire are briefly described in the following section. Information from 17 countries is included. For this purpose, UK and Northern Ireland were considered as two countries, since there is a considerable transfer of glass eels from the "UK" to Northern Ireland.

#### A. Does your country buy eels for stocking?

Yes: 11 (DE, PL, N.Irl, SE, NL, BE, FI, EE, LT, LV, DK)

No: 6 (FR, ES, PT, UK, IE, NO)

A clear geographical pattern can be seen. Countries at the Atlantic coast do not buy eels whereas countries further east of the Atlantic, and in particular around the Baltic Sea, usually purchase eels for stocking.

It has to be noted that this is a dynamic picture, which may change from year to year depending on several factors (availability and price of glass eels, situation of the fishery in the respective country, political and administrative decisions).

#### B. If so which life stage, glass or yellow eels? (only countries with "Yes" under question 1)

Glass eels: 6 (DK, LT, EE, FI, SE, N.Irl)

Yellow eels (elvers, pre-grown eels): 1 (LV)

Both: 4 (BE, NL, PL, DE)

Clear changes in the stocking strategies have occurred in the past and will probably re-occur in the future depending on several factors, in particular the availability and price of glass eels *vs.* pre-grown eels from farms. New scientific results may also influence the decision for one of the stocking types (e. g. survival and growth rates of glass eels vs. pre-grown eels, gender selection based on farm densities and risk of infection with diseases from the farms). There are risks and benefits for each type, which are considered in another section of this report, and which should be considered in the stocking strategy.

#### C. How much stock was purchased in 2008?

The data for 2008 were not complete and did not allow a useful analysis. Therefore, the data for **2007** were considered here.

Total glass eels 2007: 5.7 Million individuals

Total yellow eels 2007: 5.6 Million individuals

There are uncertainties in these numbers and the data are not complete for all countries (but all 11 countries which answered "yes" under question A, are included). Therefore, these numbers must be considered as minimum values. The calculation is difficult, since some countries buy glass eels and rear them in farms for a while before stocking. In some of these cases, the original numbers of imported glass eels are not available (just the numbers of young yellow eels stocked).

A rough estimate was made about the total amount of glass eels finally used for stocking. For that purpose, yellow eel numbers were translated into glass eel numbers (glass eel equivalents) by correction factors usually used in Denmark (1 farmed eel equals 1385 glass eels; M. I. Pedersen, pers. comm..) and Germany (1 farmed eel equals 3 glass eels; e. g. Knösche *et al.*, 2004).

Based on these factors, the total numbers of glass eel (equivalents) used for stocking ranged from 13.5 Millions to 22.5 Millions. If a mean weight of 0.3 g for glass eels is assumed, these numbers translate into biomasses of 4.5 t to 7.5 t. Even though these are rough estimates, they may indicate the order of magnitude of glass eels used for stocking of natural waters in Europe. If this is compared to the total glass eel catch in Europe, which was between 50–60 tons in 2007, a proportion of 7.5–15% of the total glass eel catch was used for stocking. This is in the same order of magnitude as previous estimates. These figures may be influenced by incomplete recordings of stocking as well as of glass eel catches.

#### D. From where or whom?

It does not appear possible to provide very clear analyses about the trade paths of glass eels since the situation is very dynamic or poorly reported (Figure 5.1). Glass eels are mainly purchased from France or from the UK. However, even glass eels bought from the UK, may previously have been imported from France. When pre-grown eels from farms are used for stocking, they are either imported as glass eels and reared in farms within their own country (e. g. DK, NL, partly DE, LT) or directly imported as young yellow eels (mainly from NL, DE, but possibly also DK and in smaller amounts from other countries). The information is probably incomplete.

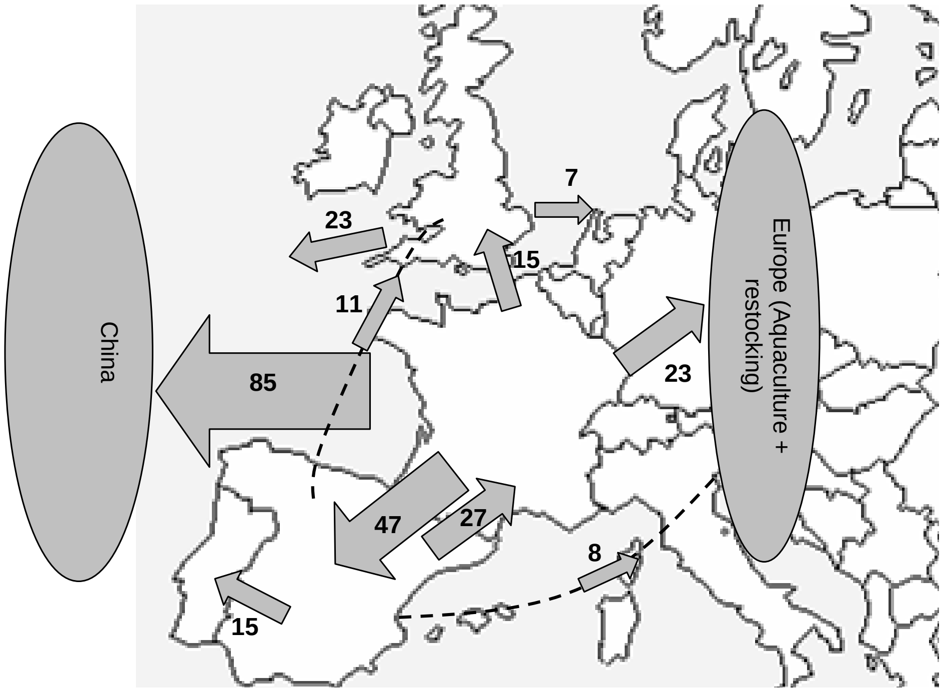


**Figure 5.1: Mean trade volumes of glass eel (T) 1996–2006 in Europe analysed from EUROSTAT database.**

The analysis of the questionnaire demonstrated that at present it is not possible to trace the origin and trade paths of glass eels and young yellow eels. However, as a consequence of the obligations in 2009 from CITES and from the EU Council Regulation (1100/2007-the "Eel Regulation"), Member States have to develop systems for the traceability of traded eels. Consequently, the availability of information on numbers/biomasses of eel traded and their trade paths are expected to improve in the future.

### E. Does your country have a protocol in place by which it stocks its waters?

| | |
|---|---|
| Yes: | 6 (DE, ES, SE, UK, EE, DK) |
| No: | 7 (PT, PL, LT, LV, IE, NO) |
| Will be developed: | 1 (BE, NL) |
| No info/unclear status: | 3 (FR, FI, N.Irl) |

The information shown here contains some uncertainties. The type of protocol may be very different between countries. It may contain just rules on were to place the eels and at what density whereas in other cases a screening for diseases or parasites may be included. Other countries are at the stage of developing protocols at present. The situation may even differ within one country if regional authorities or government are responsible for fisheries issues as is the case in Germany. A considerable number of countries do not have protocols in place suggesting room for further improvement in this area.

### F. Does your country intend using stocking as a tool in its eel management plans?

| | |
|---|---|
| Yes: | 12 |
| No: | 1 (NO) |

Still in discussion: 2 (IE, FR)

Unclear/no information: 2 (PT, FI)

The majority of countries intend to use stocking as an option in the Eel Management Plans. This raises the question if, given the possibility of a further decline in glass eel catches and the obligation to achieve the management targets also in the donor catchments, sufficient numbers of glass eel will be available to reach the stocking targets. However, the decision whether the export of glass eel from those catchments (mainly in France and the UK) to other countries for stocking will be permitted, includes an economic and political dimension, which is difficult to assess.

## 5.4 Decision framework

The WG has presented and made use of various decision frameworks in our earlier reports (ICES 2006 and 2007; Williams and Aprahamian, 2004; Symonds, 2006; Montreal report (Williams and Threader, 2007)).

### 5.4.1 Management policies

#### 5.4.1.1 Objectives

"Whenever stocking of fish is to be considered, the aims and specific objectives of the exercise must be clearly defined and adhered to" (Cowx, 1999).

Only more recently has stocking been done to mainly enhance local stocks in order to improve or provide the basis for a profitable fishery. In some circumstances stocking was done to mitigate or compensate for depleted stocks, as a result of upstream dams related to hydropower. Such stocks may be depleted as a consequence of dams as migration obstacles for young ascending eels and as turbine-induced mortalities in silver eels.

Concurrently with the awareness of the serious decline in the European eel stock and in connection with the preparation of eel management plans, stocking has become one measure to improve the stock. This time stocking is done with the main purpose of increasing the production of silver eels leaving the managed unit and contributing to the spawning biomass, i.e. not to support a fishery.

COM has proposed stocking in waters with free access to the sea as one measure among others to enhance local stocks with the ultimate goal aim to increase the biomass of spawners to produce a sufficient number of recruiting glass eels (COM 1100/2007).

Stocking as part of management plans may also occur in new water bodies, or areas where eel are absent, in order to produce additional potential spawners where access to the sea is open.

Another objective might be to restore local stocks in order to improve or preserve biodiversity (Verreault, pers. comm.) and this also might be beneficial if there is an olfactory cue to upstream migration. Alternative strategies to stocking have to be considered and analysed. Improving the possibilities for eels to migrate upstream might be a sufficient measure where dams are obstructing upstream migration, given that the emigration route is secured. Improved environmental conditions in eel growing waters, thus increasing survival and growth, may also be an alternative or addition to stocking.

As there is a general lack of stocking material (glass eels) there is no room for a misuse of this restricted resource. Therefore stocking should only be done as part of a management plan ensuring a significant escape of silver eels. The potential availability of central funding through the European Fisheries Fund (EFF) to support stocking for enhancement purposes, may ensure parity with other competitors for seed stock (e.g. aquaculture, fisheries enhancements).

### 5.4.2 Ecological considerations

#### 5.4.2.1 What size of eel should be stocked?

There are three main options; stocking of glass eel, young yellow eels and ongrown eel from aquaculture. Apart from that there is the option of moving eels "over the dam" in cases of migration obstructions (assisted migration). The latter option is not dealt with here.

The risks concerned with diseases, parasites, biased sex-ratios and genetic selection may best be avoided by stocking with eels that are as young as possible from a natural state. Stocking with yellow eel caught in the wild poses the additional risk of their being contaminated. If ongrown eels from aquaculture are considered for stocking, there are risks of disease spread, reduced genetic fitness (Section 5.4.2.3) and skewed sex ratios. When purposely infected with herpes virus in aquaculture, as seems to be widely practised, when these eels are stocked the spread of disease is a certainty, not a risk. However, stocking of healthy ongrown eels will result in comparable growth rates and mortalities compared to the stocking of glass eels (ICES, 2007).

Another risk associated with using ongrown eels, is the stocking of *Anguilla rostrata.* Stocking of *A. rostrata* seems to have occurred in the past (German Country Report, 2008; Ubl and Frankowski, 2008), *A. rostrata* is grown in European aquaculture and discrimination between *A. rostrata* and *A. Anguilla*, when grown up, is not possible in practice.

#### 5.4.2.2 Contaminants

One of the potential ecological and environmental risks which stocking programmes should consider is contamination as a potential risk to produce (in stocked systems) reproducers not able to reach spawning grounds at the Sargasso Sea and/or produce enough gametes of high quality.

Consideration should be given to pollution with PCBs, flame retardants, pesticides and heavy metals. Priority should be given to those sites where such contaminants are absent or at permissible levels (information available through the European Eel Quality Database Chapter 6).

Detrimental effects of pollution on fitness and fecundity have been suggested earlier on (Larsson *et al.*, 1990), but recently, there are indications that poor quality of the spawners, namely the silver eels migrating to the oceanic spawning grounds, might be a key factor in the decline, e.g. decrease of body fat content. Palstra *et al.*, 2006 argued that gonadal levels of dioxin-like contaminants, including PCBs, in eels from most European locations impair embryonic development. Pollution might also impact reproductive success through effects on genotype: a significant negative correlation between heavy metal pollution and eel genetic variability was reported by Maes *et al.*, 2005. Insufficient condition and energy resources (Svedäng and Wickström, 1997), high bioaccumulation of persistent organic pollutants (especially polychlorinated biphenyls-PCBs) (Larsson *et al.*, 1990; Robinet and Feunteun, 2002; Palstra *et al.*, 2006) and pathological agents (Palstra *et al.*, 2007) have been reported as potential restrictive factors, disabling long distance migration and successful reproduction with prime quality gametes.

Where spawner quality is poor and lipid content low, silver eels may not contribute to the overall spawning and recruitment of the European stock. Accumulation of energy through lipid storage may be affected by different environmental factors such as disease agents, changes in food availability, other global changes in the environment, changes in (density-dependent) sex ratios even life-history characteristics, i.e. restocking itself and pollution pressure as a consequence of disruption of the endocrine processes.

#### 5.4.2.3 Genetics, diseases and health issues

##### Genetics

The importance of maintaining genetic diversity can be divided into a short-term impact (in the order of few generations), by avoiding inbreeding and fitness decrease (population survival) and a long-term impact (over decades or even centuries), and by conferring the possibility to adapt to changing conditions (species survival). Genetic data may help to assess species integrity within the North Atlantic, evaluate the genetic stock structure of the European eel, clarify the spatio-temporal stability of the genetic structure, define the influences of oceanic conditions on genetic variability, monitor and guide the stocking policy in Europe, and evaluate the effect of population decline and habitat degradation on genetic variability and the overall fitness of eels (see also **Annex 4** for a more detailed review).

##### Genetic consequences of stocking practices

Below are listed some important points to consider in regards to genetics when planning stocking measures and provide some advice for sustainable stocking.

1 ) Deciding on mass stocking practices to supplement populations can lead to the rapid introduction of non-native genetic material from non-indigenous eel species. Monitoring the correct species identity (tracing) is therefore crucial to preserve genetic integrity of the European eel. Examples of this phenomenon have already been observed, mainly in Germany (Trautner *et al.*, 2006), where *A. rostrata* were found, prompting for up to date molecular identification methods for species discrimination (Maes *et al.*, 2006a). The European eel has been listed under CITES, potentially leading to increased importations of other eel species. Such exotic eel introductions have been a major problem in Asia, where European eels were introduced to supplement Japanese eel stocks (Okamura *et al.*, 2002; 2004).

2 ) Aquaculture grown glass eels (grown from glass eels to 10 cms) are often used for stocking purposes. Although at first sight no significant problem is expected from the genetic diversity point of view (glass eels are natural recruits), potential consequences could be other than expected. Indeed, keeping glass eels too long in such facilities will adapt them to aquaculture conditions (such as artificial food and temperature regimes), and will lower their competitiveness in the natural environment. Currently juvenile eels are deliberately exposed to water contaminated with the highly virulent Herpes virus *anguillarum* (HVA) in order to induce a limited infection which, although causing some mortality, will autovaccinate the fish prior to them meeting the infection at the most vulnerable fast growing stage. This process causes a significant drop in food intake and growth rate but is considered the lesser evil by the industry at present in the absence of an approved commercial vaccine. As such, ongrown eels used for stocking which have been reared under such practices pose an epidemiological

threat given that they can infect natural populations. Additionally, such practices create a high selective pressure on glass eels, reducing total genetic diversity and directionally selecting at the functional level for specific disease resistance genes (such as MHC). This has been revealed to have a very detrimental effect in salmonids when such individuals are released in the wild, as a consequence of a lower fitness for natural pathogens. Timing of stocking should be carefully considered in order to optimize survival. Stocking material should not be composed of the slow growers of aquaculture, which have been revealed to exhibit a lower functional genetic diversity and could demonstrate lower survival rates and skewed sex ratios.

3 ) At the population level, stocking practices can have major consequences on intraspecific biodiversity, as a consequence of the mixing of genetically differentiated populations. No stable geographical differentiation has been detected to date (Wirth and Bernatchez, 2001; Dannewitz *et al.*, 2005; Maes *et al.*, 2006). However, given long-term stocking practices since the 1950s, it is possible that these might contribute to a homogenization of populations as a consequence of massive translocations. Indeed, the presence of only a small level of geographical genetic differentiation at neutral genetic markers may lead to seriously underestimating of quantitative and adaptive differentiation between populations. From recent studies on marine fish populations we know that adaptive differences might be present but not detectable with the current molecular markers. Indeed, apart from analysing neutral genetic variation to assess the demographic independence and stability of fisheries stocks, knowledge of geographic and temporal scales of adaptive genetic variation is crucial to species conservation (Conover *et al.*, 2006; Maes and Volckaert, 2007). If distinct populations exist, the introduction of genetically different glass eels can potentially break up any existing adaptation in local stocks and have major fitness consequences on life-history traits, such as migration duration and timing, temperature resistance and size at maturation sizes. The homogenization of these traits can lead to a decrease in diversity and the loss of important traits for survival. However, given these concerns and the absence of data the following advice for different levels of natural recruitment is therefore precautionary.

Regions with no recruitment: stock with glass eels in high quality habitats originating in if possible the same main hydrographical region (Northern Europe, West Atlantic, Southern Europe, Mediterranean).

Regions with low recruitment: Preserve natural recruits, while preferably stocking glass eels from estuaries or neighbouring river basins in high quality upstream habitats.

Regions with high recruitment: care should be taken not to overfish glass eels for stocking purposes, as this will weaken the donor region and deplete the rivers from escapees.

If neither neutral nor adaptive differences can be detected in the European eel, stocking practices may have a beneficial effect. However, the question remains, whether stocked individuals will find their way to the Sargasso Sea and ultimately contribute to the spawning stock. The most important issue is then to preserve the total genetic diversity to allow adaptation to a changing environment. Keeping the highest level of biodiversity in phenotypic (quantitative) and genetic traits is crucial to the survival of the entire species.

#### Pathogens and parasites

The occurrence of diseases and parasites in eels has been recorded for some time. Up to now, consequences on the ability of eels to carry out their long-distance migration and reproduction were unknown, although these have been suggested as potential causes for the decline in eel populations. Available information on the introduction and spread of *A. crassus* in Europe illustrates how through live-transport of eels, within and between countries, and through stocking programmes the parasite has been rapidly dispersed to all major spawner producing areas.

In the proceedings of a recent workshop held in Montreal (Canada) in 2007, the risk of disease transfer when stocking eel was specifically addressed (Williams and Threader, 2007) because eel transfers increase the risk of pathogen introduction. In her review, Symonds, 2007 described several parasites, viruses, bacteria and fungi that have been found in eel communities in North America. In Europe, many studies on eel parasites and diseases indicate that stocking and transfers have been responsible for rapid spreading of their fellow travellers (Szekely, 1994; Van Ginneken *et al.*, 2004; EELREP 2005). The rapid spread of *A. crassus* throughout Europe indicates that eel transfer or stocking done without screening is a practice that can be detrimental for the population and aquatic community.

In Canada eel stocking and transfers must be done under "The National Code on Introductions and Transfers of Aquatic Organisms" to avoid risks to aquatic animal health from the potential introduction and spread of pathogens and parasites that might accompany eels being moved. Screenings are routinely done for elvers before their stocking in fresh-waters locations. Screenings for viruses (IHNV, ISAV, IPNV and EVH) and *A. crassus* in individuals prior to stocking were negative since the initiation of the stocking programmes, four years ago.

In spite of warnings concerning viruses and diseases issued from WGEEL in 2006, there is still no common protocol for parasite and disease screening prior to stocking. Each country applies its own regulation and screening procedure for stocking. For example, Sweden practises quarantine for imported glass eel prior their stocking in brackish and fresh-water areas whereas no specific procedures are in place for other countries. Table 5.1 shows what is done for each European country prior to glass eel and/or elver stocking to prevent the introduction of parasites, viruses and pathogens.

It appears that few countries have put in place procedures to prevent the introduction and spreading of parasites and diseases when stocking young eels. This could be very detrimental for the future of eel populations since stocking will presumably be part of many national Management Plans. A robust protocol for screening stocked stocks should be put in place as soon as possible.

**Table 5.1: Current procedures for stocking glass eel/young eel to European countries.**

| Country | Stocking | Screening for parasites, viruses and pathogens | Quarantine |
|---|---|---|---|
| Belgium | Yes | No | N0 |
| Denmark | Yes | Yes | Yes |
| Estonia | Yes | Yes | No |
| Finland | Yes | Yes/No | Yes |
| Poland | Yes | No | |
| France | Yes | No | No |
| Germany | Yes | Yes/No | No |

| Country | Stocking | Screening for parasites, viruses and pathogens | Quarantine |
|---|---|---|---|
| Ireland | Yes1 | No | No |
| Italy | No | - | - |
| Latvia | Yes | No | No |
| Lithuania | Yes | No | No |
| Netherlands | Yes | No | No |
| Norway | No | - | - |
| Portugal | No | - | - |
| Spain | Yes | Yes | - |
| Sweden | Yes | Yes | Yes |
| UK | Yes | Yes*/No | No |

**[1]Stocking restricted within the same water catchment.**

*** For England and Wales only.**

### 5.4.3 Fisheries considerations and considerations for other users

Generation times of eels decrease with temperature and increase with latitude and may be 2–3 times lower in the most Southern parts of the distribution range as compared to the Northern parts of Scandinavia. Growth of eels varies between 14–62 mm.year$^{-1}$ within its distribution range (ICES, 2006) and this means that for male silver eels of 37 cm it will take then 5–21 years to reach that size. For female eels of 67 cm it will take twice as long, while for longer females it will take even longer. If the glass eels were stocked in 2009, the effects on silver eel escapement could be expected from 2014 (at the earliest) to approximately 2050, depending partly on stocking location and partly on sexual differentiation and eel growth. Therefore this is a measure that might be valuable over a longer time-scale. If the stocked eels are not hampered by anthropogenic factors, they could contribute significantly to silver eel escapement after 10 years or more. Eels stocked in suitable habitats may well grow faster than if left *in situ* and, therefore, mature earlier (Aprahamian, 1988).

#### 5.4.3.1 Effects on recipient eel populations

The surface area of available habitats in Europe is estimated at 5–10*10$^6$ ha (ICES, 2005). A possible stocking of 60 tonne (at most) when well spread over the available habitat, will have no significant negative effect on the growth of the existing eel populations. However, if high stocking rates are applied locally, this will be different because of density-dependent growth rates (reviewed by ICES, 2007).

Effects on existing populations may occur when stocked eels are diseased. Change in sex ratios (as demonstrated on Lough Neagh under differing recruitment and stocking patterns (Rosell *et al.*, 2005)), in favour of males, potentially affecting the yearly production of the non-stocked eels. Effects on the whole stock may occur if the genetic fitness of the stocked eels is further reduced. The latter might occur when stocking eels from aquaculture without additional care for reducing possible genetic effects.

#### 5.4.3.2 Effects on the remainder of the exploited fishery

The effects on the fishery depend largely on the total quantity of eels to be stocked. If the aforementioned 35–60 tons would be stocked, it has a yield potential in the same order of magnitude as the eel aquaculture production in Europe or the current eel landings in Europe. This potential would be fully realized after one generation time. If not fished at all, this would increase the production of silver eels (ICES, 2006). The quantity of 35–60 tons of glass eels is more or less equal to, or more than the historical maximum of stocking rates (40 tons).

#### 5.4.3.3 Effects in mixed-stock fisheries

There are no additional effects expected in mixed-stock fisheries.

### 5.4.4 Implementation constraints

#### 5.4.4.1 Introduction

Cowx, 1999 recognized a number of potential constraints associated with any stocking programme, and posed these as a series of checks for managers, regarding the availability of:

- sufficient quantity and quality of fish;
- suitable methods of the transportation and expertise;
- sufficient funds; and,
- have the access rights been defined.

The issues of funding for stocking programmes, and access to donor and recipient waters are political rather than scientific issues, and so we will not consider them here. The first two bullet points have been considered previously by ICES (2006, 2007) and others (Williams and Aprahamian, unpublished; Symonds, 2007; Montreal, 2008). Here, we summarize the outcomes and update supporting materials where they have become available since the 2007 report was compiled.

#### 5.4.4.2 Are sufficient quantities of eel available for stocking, at the local level?

At the local or catchment level, there may be a surplus stock of glass eel, arising as a result of density-dependent mortality being higher in the absence of fishing (ICES, 2006). The prime assumption for a local surplus of eel is that removing the eel has no impact on the donor population (on silver eel output). That is, reductions in density-dependent mortality (or other limiting effects such as growth rates and gender determination) result in enhanced production of silver eel in the stocked population exceeding the putative loss (from fishing elvers) in production from the donor population.

Lobón-Cerviá and Iglesias, 2008 studied long-term variations in the density of eels in the Rio Esva (northwestern Spain) at an estuary site and at nine sites distributed among three tributaries (1986–2006). Mortality rates calculated for age cohorts revealed a consistent positive trend, with 53.3% of the variation in cohort mortality rate explained by variation in glass eel abundance. Note, however, that this population is characterized by fast growing and early maturing eels, almost all of which become male.

Although the Regulation (1100/2007) does not specifically require that eel for stocking are sourced only from catchments where such a surplus exists, it is prudent to focus collection on such catchments. However, previous ICES reports and other reviews have provided little guidance on how managers could assess whether a surplus exists, and thereafter, quantification of this surplus.

The direct means for this assessment is to quantify the size of the donor population, typically glass eel, and compare this with estimates of the amount of settled elver required to produce the target silver eel output. The EU InterReg programme, Indicang, considered methods for the absolute quantification of glass eel in estuaries, recommending flux quantification (filtration) or mark recapture exercises, but noting that these methods are difficult in large and stratified estuaries (Feunteun, pers. comm.). Alternatively, an indirect assessment can be made based on studying the associated yellow eel population under conditions of varying glass eel exploitation to establish lack of impact of said fishery. For example, a glass eel fishery in the Severn estuary, England, does not yet seem to have had any measurable negative impact on upstream stocks of eel (See UK country report 2006).

ICES, 2006 discussed the concept of the carrying capacity of eel in relation to deciding whether to stock eel in a water body, but it should be considered also in deciding whether a potential donor water body can sustain the loss of eels to be stocked elsewhere.

There are two considerations; immediate effects of loss to the estuary, and subsequent effects to the yellow eel population and silver eel output from the river basin.

A method of calculating carrying capacity of a river or lake for eel has not been identified; in part as a consequence of the difficulty in assessing density and/or biomass of eel accurately in a given body of water (Williams and Aprahamian, 2004). Whether a site is at carrying capacity is linked to ease of access for colonization and the productivity of the water.

In tributaries of the lower Severn, Aprahamian, 2000 found eel density ranged from 0.12-1.14 $m^{-2}$ and biomass from 2.56–25.24 $gm^{-2}$. The absence of any relationship between growth and either density or biomass, suggests that the sites were limited by their productivity and may indicate that they were close to or at their carrying capacity, defined as the maximum density or biomass that the habitat can sustain under average conditions.

In the southern part of their range the carrying capacity is likely to be higher as a consequence of higher temperatures and productivity resulting in a shorter generation time, even if extremely variable among sites. No recent evaluations are available, but given the potential for spawner production of those environments, the enhancement of evaluation studies on this aspect is recommended. Greater importance should be given to biomass when trying to assess whether a site is or is not at carrying capacity. This is because there is a smaller variation in biomass when compared to density both within and among river systems (Aprahamian, 1986) and it is more related to carrying capacity (Knights *et al.*, 2001).

The analysis of eel fishery ‘outputs’ from L. Neagh in relation to glass eel stocked (ICES 2007) suggests a density-dependent relationship with a negative exponential between input stock and eventual output. That is, outputs are maximal for inputs in the range of 150 to 200 glass eel per hectare.

Similarly, Knösche *et al.*, 2004 give a formula, how to estimate the recapture rate in the fishery after stocking for a range of common stocking densities for German waters (50–00 glass eel equivalents per hectare).

Recapture rate (%) = 611 * stocking density $^{-0.81}$

Thus, at a stocking density of 50 glass eels/ha, this would result in a recapture rate of 26%, whereas at 500 glass eels/ha it would decrease to 4%.

However, the general lack of information on carrying capacity in eel populations noted by ICES 2006 continues to this day.

A method of calculating carrying capacity of a river or lake for eel has not been identified, in part as a consequence of the difficulty in assessing density and/or biomass of eel accurately in a given body of water (Williams and Aprahamian, 2004). Whether a site is at carrying capacity is linked to ease of access for colonization and the productivity of the water and recruitment. However, the general lack of information on carrying capacity in eel populations noted by ICES 2006 continues to this day. The most likely sources of eel for stocking (and seeding ongrowing facilities) are glass eel fisheries in estuaries, and traps where upstream migrating eel are concentrated, such as eel passes on weirs and dams. In considering the effects of removing glass eel from estuaries and lower reaches of rivers, the carrying capacity of the estuary may be important. There is, however, no information currently on this, and it is an area that should be addressed. A study group to address this area has been proposed to the Diadromous Fish Committee 2008.

#### 5.4.4.3 Potential indirect impacts on donor stock

ICES, 2006 noted that under the current situation of critically low stock levels, removal of glass eel from any site to stock another should only be done with a full assessment of the effect on recruitment into the growing areas dependent on that donor site. In addition to the direct effects on the size of the local population, there are two other potential risks with removing glass eel from the donor site, a reduction of dispersal of juvenile eel to upstream habitats, and possible alterations to sex ratio of silver eel.

Upstream migration may be driven by intraspecific competition and higher densities downstream. For example, the construction of an estuarine dam on the Vilaine prevented recruitment of eels for 25 years, but the installation of an eel pass resulted in a density-dependent migration behaviour; 1+ groups being forced into the periphery of the high-density area (about 0.8 eels $m^{-2}$), which extended further upstream in successive years (Feunteun, 2002). Note, however that this "wave" type migration, is in contrast to that reported by Ibbotson *et al.*, 2002 for eels colonizing the River Severn where upstream migration was mainly through diffusion. Removal of stock from downstream areas may reduce the propensity for colonization of upstream areas.

Although the physiological mechanisms for gender differentiation in eel (reviewed by Davey and Jellyman, 2005) are still unclear, evidence supports the concept that it is density driven. There is a risk that removing glass eel from estuaries will affect subsequent gender differentiation and sex ratio of yellow eel (and hence silver eel). Transporting undifferentiated eels from high to relatively low density habitats may well influence ultimate sex ratio of the silver eel output, and by association, the weight of output and distribution across time.

#### 5.4.4.4 Issues of ownership

In considering where to stock, managers must evaluate the subsequent potential exploitation and other mortalities of the eel, e.g. fisheries, turbines, etc. There may be a number of users who potentially benefit from the stocking, and therefore, they should all contribute to funding of the stocking.

## 5.5 Artificial reproduction of eel

### 5.5.1 Introduction

Summary of the main findings relevant to WGEEL from the *European Aquaculture Society Thematic Group Workshop on European Eel Reproduction* (October 24th, 2007, Istanbul).

Given the complex nature of the eel life cycle and that maturation occurs during the oceanic phase there is very little information on natural maturation and reproduction.

Consequently much of this work is derived from laboratory studies which examine the environmental effects, endocrine control and artificial reproductive techniques on the production of larval European eel. Details of abstracts on this work can be found at http://www.easonline.org.

The onset of sexual differentiation in eels:

Studies from Israel into the hormonal development in young farmed eels <25 cms found a difference in the hormones released from the pituitary gland depending upon the density of eels held in tanks. Those with fewer eels in them, developed into female eels associated with the hormone release of the female hormone estradiol, while those in higher densities became male associated with the release of the male hormone 12 Keto-testosterone.

### 5.5.2 Silver eels

Several studies presented evidence that silver eels leaving continental Europe should be considered as being in a pre-pubertal state given that swimming appears to be a strong natural trigger for the development of advanced maturation. During the swimming phase lipid stores in the eel are utilized for the production of energy to fuel their migration and to produce gametes through a variety of hormonally induced metabolic pathways. Research into the thermodynamic influence of hydrostatic pressure on swimming ability found that the metabolism of the eel's fat stores was much more efficient at depth thus optimizing their energy expenditure during migration. Once they have arrived at the spawning grounds several studies into the olfactory capabilities of silver eels and their reactions to specific eel odours suggested that olfaction maybe crucial to synchronizing final maturation in both sexes.

### 5.5.3 Embryo and larval development

The natural development of embryos appears to be influenced by hydrostatic effects (that had not been used previously during artificial attempts at fertilization) which induce a slower egg cleavage rate and thus embryo development period. It's likely that this may be caused by the pressure influence on thermodynamics and or mechanical stress on egg membranes and water transfer through them at these depths.

Despite many previous attempts to artificially breed European eel the hatching of larvae has only been achieved on a few occasions with a maximal larval life of 3.5 days. The main obstruction has been the intricate hormonal control mechanisms that inhibit gonadal maturation at the onset of puberty. Repeated hormonal treatments to produce gametes have been successfully applied to produce viable eggs and larvae of the Japanese eel. Similar methods have been applied to the European eel, but deficiencies in genitor quality causing fertilization failure had hampered the ability to produce larvae in the past. Investigations into the failure found that an essential fatty acid was missing from the feed given to the broodstock which when included produced fertile eggs. Mass hatchings from these eggs have been achieved and the larvae were fully developed and ready to feed 12 days post-hatching. However further development of the larvae past this stage failed as a suitable feed has yet to be found/developed.

### 5.5.4 Artificial reproduction techniques

The hormonal induction of maturation is a fundamental requirement for artificial reproduction but this presents difficulties in terms of synchronizing the development of males and females. To aid this cryopreservation techniques have now been developed for eel sperm which yielded viable eel sperm several months after deep freeze storage. Prior to storage the hormonal induction of the males yielded sperm after four weeks the quality and quantity of which increased up to eight weeks after induction. Developments in the maturation of females have found that low initial temperatures increase the sensitivity of the female and that temperatures <17°C during gonadal maturation produced better results.

### 5.5.5 The Japanese Experience

Japanese glass eel were successfully produced in captivity in 2005 (Kagawa *et al.*, 2005), and since then this work has progressed to produce hybrid larvae of European (male) and Japanese eel (female). The success of this work has relied heavily upon the production of a suitable feed for the larval stage, details of which are currently contained in a Japanese Government registered patent.

## 5.6 Conclusions for Chapter 5: Stocking and aquaculture

### 5.6.1 Potential benefit of stocking to regenerate the stock

At present, it is estimated that around 7.5 to 15% of the glass eel catch is used for stocking, either directly or as on-grown eels. Estimates suggest an insufficient supply of glass eel from the total fishery for stocking to full capacity at the European level. Nevertheless, the Regulation 1100/2007 requires that 35%, rising to 60%, of glass eel catches are made available for stocking to enhance the stock. If these percentages were applied to recent annual catches of glass eel, the potential lifetime effect of this increased level of stocking, in the absence of anthropogenic mortalities, could be in the same order of magnitude as current fisheries or eel culture. However, there is a continuing and urgent requirement for robust evidence of the extent to which stocking and transfers on local, national and international scales can increase silver eel escapement and spawner biomass.

The general lack of information on carrying capacity in eel populations noted by ICES 2006 is still an issue hampering management of eel.

### 5.6.2 Identifying local surplus

It is anticipated that assessments conducted for EMPs will decide whether or not there is a local supply of eel sufficient to meet demands for stocking (either within catchment, RBD, nation or elsewhere in Europe). However, there is a limited understanding on methods by which to make assessments of a local surplus on a quantitative, biological basis.

### 5.6.3 Post-evaluation of the net benefit of stocking

The assessment post-evaluation of the contribution of stocking to silver eel production is still hindered by the limited quantitative information available on survival/mortality rates (stage specific and glass eel to silver eel), both for stocked eel and wild/natural eel for comparative purposes, for habitats representing the variety available across Europe, and especially for stocking in rivers.

### 5.6.4 Risks of stocking

It appears that few countries operate procedures to prevent the introduction and spreading of parasites and diseases when stocking young eels and this could be detrimental for the future of eel populations since stocking will presumably be part of many national Management Plans. The risks remain of disease and parasite transfer via stocked material, potentially both from the 'wild' and on-grown in aquaculture. For example, the practice of aquaculture in terms of viral inoculations needs to be addressed. A robust protocol for screening stocked stocks should be put in place as soon as possible.

New techniques are currently used for genetic analyses of the eel stock and results are expected in a few years. These results may prompt a re-assessment of the potential risks associated with stocking.

There is a clear need for assurance that donor populations are not impaired by the removal of glass eel. Notwithstanding the potential risks to the donor population, it is anticipated that assessments conducted for EMPs will determine whether or not there is a local supply of eel sufficient to meet demands for stocking (either within catchment, RBD, nation or elsewhere in Europe).

### 5.6.5 Aquaculture/on-growing to support stocking for enhancement

Spawner quality in terms of levels and composition of lipids and contaminants appears to be a key issue for the success of both natural and artificial reproduction. Given the future requirements for stocking glass eel or deciding to stock on-grown eel, the implications of the findings on hormonal release and subsequent gender development depending upon stocking densities must be considered.

Spawner quality in terms of lipid levels and contaminants appears to be a key issue for the success of both natural and artificial reproduction.

## 5.7 Recommendations

### 5.7.1 Methods to support the basis of stocking for enhancement purposes

The WG recommends that developing methods to make assessments of local surplus of stocking material on a quantitative, biological basis is a priority for research in the near future. Data to post-evaluate the relative contribution of stocking to silver eel production can only be supplied by experimental studies, and although acknowledging that some studies are ongoing, we recommend concerted action to address this area, especially with regard to stocking in rivers, and the relative performance and yield-per-recruit of stocked cultured eels compared with glass eels.

A study group to address eels in saline habitats has been proposed to the Diadromous Fish Committee.

### 5.7.2 Risks associated with stocking

The eel should be included in the European fish disease prevention policy in order to minimize the risks of transfer of diseases associated with stocking.

A robust protocol for screening stocked stocks should be put in place as soon as possible.

Purposely infected eels in aquaculture with pathogens (viruses, etc.) should not be used for stocking purposes.

The culture of *A. rostrata* in European aquaculture will make it impossible to discriminate between stockings of *A. anguilla* and *A. rostrata* and should be avoided; the same applies to possible growing of other eel species in the future. The improved systems to trace glass eel trade, for CITES and the Regulation (EU 1100/2007), should facilitate this, and the WG strongly support these developments also to address the risks highlighted here. Besides the Eel Regulation and CITES, the following EU Council Regulation (EC) N° 708/2007 concerning the use of alien and locally absent species in aquaculture is also likely to allow better control of farmed alien species like *A. rostrata.*

Despite limited evidence and a complicated variety of possible impacts of environmental factors, such as contaminants, on silver eel quality, conservative advice remains that stocking for stock enhancement purposes should not be conducted in waters heavily polluted with substances that might pose risks for spawner quality.

# 6 Eel quality

## 6.1 Introduction

In recent years (e.g. ICES, 2006) the Working Group has described the risks of deteriorated biological quality of eels. In 2005 the EU-EELREP programme (Estimation of the reproduction capacity of European eel) concluded that contamination with PCBs impaired fertility while infections with pathogens and parasites were devastating for swimming eels.

The recommendations of the WG EEL 2006 highlighted the need to monitor and to collect information on (1) **pollution and disease** to be able to designate areas producing high quality spawners (e.g. with **low contaminant and parasite burdens** in order to maximize protection for these areas; and (2) the **chemical status** of eel under the implementation of the WFD.

An increasing level of evidence on the detrimental impact of contamination and diseases on the eel has been made available.

ICES 2007 reported on the advances made in the collection of data on contaminants, parasites and fat levels in eel, and reported that many Member States started the monitoring of eel quality. In 2007, the WGEEL initiated the set-up and development of a European Eel Quality Database (EEQD), allowing the compilation of a comprehensive overview on the contaminant load in eel over its distribution area. Results from the EEQD demonstrated that considerable variation in contaminant load exists within river basin districts, according to local anthropogenic pollution, linked with land use. There is evidence that, on a pan-European scale, large differences in eel quality occurs between catchments. Furthermore, 'black spots' with low quality eels were detected. Lipid content, which is believed to be an important index of fitness, was highly variable between sites. New evidence (Geeraerts, *et al.*, 2007) was presented on the negative impact of certain contaminants on the fitness of eel.

The recommendations of the Working Group 2007 (ICES 2007) proposed that:

1 ) MS should further develop and maintain the European Eel Quality Database.

2 ) MS should initiate harmonized monitoring strategies to develop a European Eel Quality Monitoring Network, to collect the relevant data to be fed into the EEQD. National eel management plans, should take account of these data for evaluation of the quality of spawners.

3 ) Under the implementation of the WFD eel specific extensions should be included, using the eel as an indicator of river connectivity and ecological and chemical status, and making cost-effective use of collected data, also for the benefit of the EU Eel Regulation and recovery of the eel stock.

During the WGEEL 2008 session, new scientific evidence of eel quality as an important factor in the decline of the species has been presented and discussed. The WGEEL 2008 also updated the EEQD. In the light of the introduction of the EU Regulation in 2007, the WGEEL proposed recommendations and discussed urgent research needs/demonstrated gaps in eel quality knowledge.

## 6.2 Contaminants

### 6.2.1 Introduction

Due to specific ecological and physiological traits, eels are particularly sensitive to bioaccumulation of lipophilic contaminants. From recent scientific evidence (Belpaire, 2008) there is reason for serious concern as the level of measured concentrations of some contaminants has been demonstrated to have adverse effects on the reproduction success of the silver eel.

Current gonadal levels of dioxin-like contaminants, including PCBs, in eels from most European locations impair normal embryonic development and that PCBs and other contaminants may have contributed to the decline of eel recruitment observed since 1980 (van den Thillart *et al.*, 2005; Palstra *et al.*, 2006), a conclusion consistent with the fact that the emission of PCBs in the environment (van Leeuwen and Hermens, 1995) preceded the decline of European eel.

An extensive dataset of contaminants has been analysed by statistical modelling, to demonstrate relationships between fitness (lipid content and eel condition) and various environmental variables and PCBs (especially the higher chlorinated ones) and DDTs were revealed to have a negative impact on the lipid content of the eel. (Geeraerts *et al.*, 2007).

Extensive information has already been provided in the WGEEL 2006, and 2007 reports (ICES 2006; 2007). Recently, Belpaire, 2008 compiled an overview of research on contaminants in Flanders (Belgium). The status and trends of eel quality factors and the potential role of contamination in the collapse of the stock are presented and discussed here.

### 6.2.2 The eel and the Water Framework Directive

The EU Water Framework Directive requires monitoring of a selection of priority substances in the aquatic phase, including lipophilic substances. However, there are strong arguments for measuring the latter in biota (Belpaire and Goemans, 2007a, b). Yellow eel is a good candidate because it is widespread, sedentary and accumulates many lipophilic substances in its muscle tissue. Several authors have described the indicative value of measured concentrations, yet few studies have investigated the extent to which the spectrum of contaminants present characterizes the local environmental pollution pressure. To evaluate the value of the pollution profile of an eel as a fingerprint of the chemical status of the local environment, two datasets were selected from the Flemish Eel Pollutant Network database. One set from a small catchment area to investigate site-specific profiles, and one from seven large Flemish rivers to investigate river-specific profiles. The pollution profiles of persistent organic pollutants in individual eels along a river (even at distances <5 km) proved to be significantly different (Figure 6.1). Analysis of pooled contaminant data from multiple sites and sampling years within rivers allows characterization of river-specific chemical pressures. The results highlight the usefulness of eel as a bio-indicator for monitoring pollution with lipophilic chemicals like polychlorinated biphenyls and organochlorine pesticides in rivers (Belpaire *et al.*, 2008). It was concluded that, as such, eel may be used effectively within the monitoring programme for a selection of priority substances referred to in the Water Framework Directive (Table 6.1). Some countries reported planning reporting eel quality data within the WFD chemical status report.

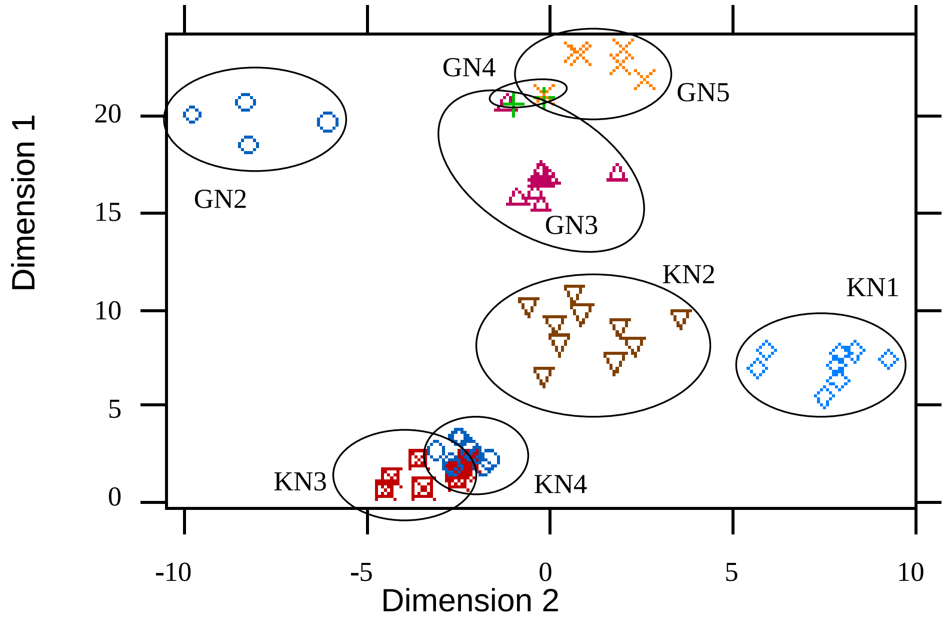


**Figure 6.1: Canonical discriminant analysis of eels collected at eight sites in the Grote Nete and Kleine Nete on the basis of their PCB and OCP concentrations (N= 61). Distance between locations varied between 4 and 20 km.**

**Table 6.1: WFD substances mentioned under CEC (2007), and available data from measurements of Flemish eels. All data are expressed in ng g$^{-1}$ wet weight. DL, detection limit (from Belpaire and Goemans, 2007).**

| Substance | Note | Range Min – Max (Mean) | %<DL | No. of sites | Years | Source |
|---|---|---|---|---|---|---|
| Benzene | a | 1.2–18.9 (5.7) | 0 | 20 | 1996–1998 | j |
| Brominated diphenylethers | a | 6.9–5 284.4 (369.1)c | 0 | 18 | 2001 | l |
| Cadmium and its compounds | a | D.L.-151.4 (11.7)d | 19 | 357 | 1994–2005 | k |
| 1,2-Dichloroethane | a | D.L.-4.9 (1,2) | 55 | 20 | 1996–1998 | j |
| Hexachlorobenzene | a | D.L.-61.6 (5.7) | <1 | 357 | 1994–2005 | k |
| Hexachlorobutadiene | a | D.L.-12.2 (1.8) | 50 | 20 | 1996–1998 | j |
| Alfa-Hexachlorocyclohexane | a | D.L.-13.7 (0.8)e | 13 | 357 | 1994–2005 | k |
| (gamma-isomer, Lindane) | a | 0.1–2 076.4 (46.9) | 0 | 357 | 1994–2005 | k |
| Lead and its compounds | a | D.L.-1 744.2 (56.6)f | 3 | 357 | 1994–2005 | k |
| Mercury and its compounds | a | 10–535.4 (113.5)g | 0 | 355 | 1994–2005 | k |
| Naphthalene | a | 1.5–63 (5.8) | 20 | 20 | 1996–1998 | j |
| Nickel and its compounds | a | D.L.-2 944.7 (186.2)h | 16 | 297 | 1994–2005 | k |
| (1,2,4-Trichlorobenzene) | a | D.L.-30.9 (6.0) | 15 | 20 | 1996–1998 | j |
| Trichloromethane (chloroform) | a | D.L.-96.0 (13.4) | 25 | 20 | 1996–1998 | j |
| DDT total | b | 6.6–1 102.7 (90.2)i | 0 | 357 | 1994–2005 | k |
| p,p′-DDT | b | D.L.-62.6 (2.9) | 38 | 357 | 1994–2005 | k |
| Aldrin | b | D.L.-11.4 (1.3) | 33 | 96 | 1994–2005 | k |

| SUBSTANCE | NOTE | RANGE MIN – MAX (MEAN) | %<DL | NO. OF SITES | YEARS | SOURCE |
|---|---|---|---|---|---|---|
| Dieldrin | b | D.L.-237.6 (19.1) | 15 | 357 | 1994–2005 | k |
| Endrin | b | D.L.-29.1 (1.1) | 80 | 346 | 1994–2005 | k |
| Tetrachloroethylene | b | D.L.-88.9 (13.4) | 50 | 20 | 1996–1998 | j |
| Trichloroethylene | b | D.L.-30.3 (2.0) | 95 | 20 | 1996–1998 | j |

**[a] Priority substances.**

**[b] Other pollutants, which fall under the scope of Directive 86/280/EEC and which are included in List I of the Annex to Directive 76/464/EEC, are not in the priority substances list. Environmental quality standards for these substances are included in the Commission's proposal to maintain the regulation of the substances at Community level.**

**[c] The data present the Sum of 10 BDEs.**

**[d] Cd.**

**[e] alpha-hexachlorocyclohexane.**

**[f] Pb.**

**[g] Hg.**

**[h] Ni.**

**[i] Sum of p,p'-DDD, p,p'-DDT, and p,p'-DDE.**

**[j] Data from Roose *et al*. (2003).**

**[k] INBO Eel Pollutant Monitoring Database.**

**[l] Data from de Boer *et al*. (2002) and Belpaire *et al*., 2003.**

### 6.2.3 Eel pollution monitoring networks-status and trends

Most of the countries submitted data on contaminants to the EEQD (see Annex 5 for Country reviews). In many sampling sites, concentration of contaminants fell and this probably reflects decreasing contaminant exposure. However, the monitoring does not evaluate the presence of new contaminants not to mention the increasing number of non-native species. Nevertheless there are widespread industrialized regions where contaminant loads still exceed reference levels.

Some countries are operating Eel Pollution Monitoring Networks on a national scale. The networks allow the follow-up of contamination in eels and allow detailed analyses of the status and trends for a specific contaminant, or a group of contaminants. They also allow detailed analysis of status and trends of contamination on a certain spatial scale (site, river, catchment, town, province, region). In some countries (e.g. Belgium) these trends can be viewed in reports via predefined queries on a national database available on the Internet, and maps are available for contamination in eel for PCBs, pesticides and heavy metals (e.g. Goemans *et al.*, 2008). As an example the distribution of PCB 156 in eel from Flanders (Belgium) is represented in Figure 6.2. This allows the indication of good and bad quality eel areas.

Eels from different river basins differ in contamination. Belpaire *et al.*, 2008 presented PCB and OCP contamination profiles for some basins in Belgium. Eels from the river Yser are characterized by high OCPs, especially dieldrin and lindane ($\gamma$-HCH), and low PCB levels. In the River Maas, PCB concentrations are high, and are dominated by the higher chlorinated (and higher toxic) PCBs.

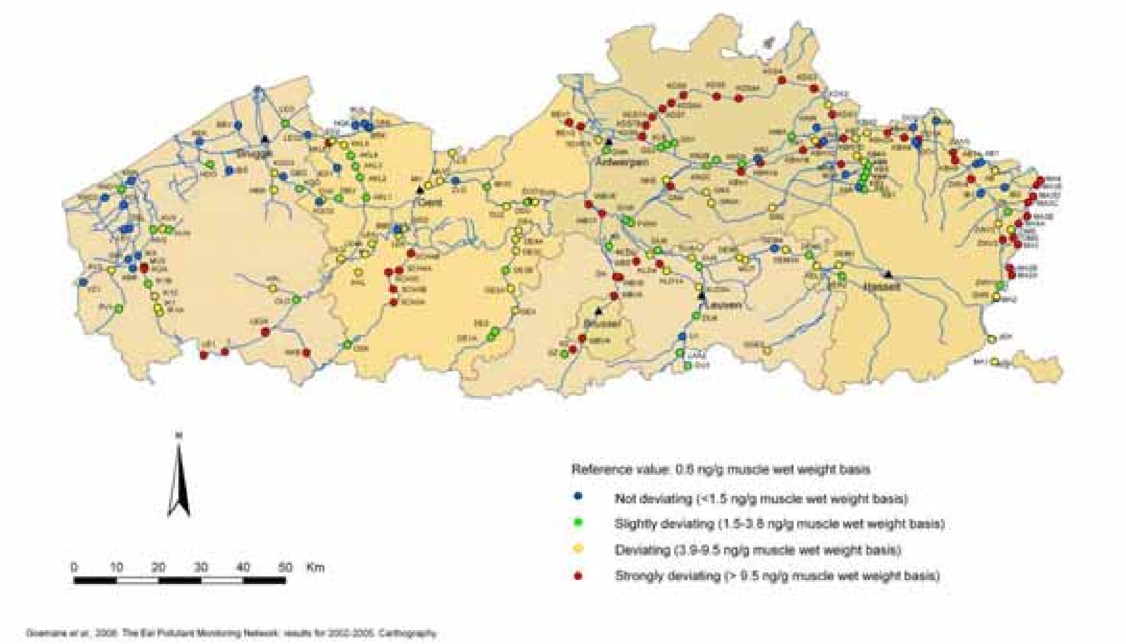


**Figure 6.2: Distribution of PCB 156 in yellow eel in Flanders (2002–2005); means on muscle wet weight basis, classified following the deviation from the reference value (Goemans *et al.*, 2008).**

High concentrations of some substances in eel tissue confirmed the previously known high pollution load of some specific areas, but in many cases however, eel analyses revealed unknown environmental problems. In a few cases analysis of eels from a specific location has demonstrated unsuspected high pollution levels of several contaminants. But several contaminants (e.g. BTEX (benzene, toluene, ethylbenzene and the xylenes) compounds, PCBs and some very persistent OCPs like DDTs) are widespread in certain countries. (Roose *et al*., 2003)

Results of measurements of dioxins on eight locations in Belgium (Flanders) indicate some reason for concern. Dioxin concentrations in eel vary considerably between sampling sites, suggesting that eel may be good indicators of local pollution levels. The European Commission has set maximum levels of 4 pg TEQ $g^{-1}$ fresh weight for the sum of dioxins (WHO-PCDD/F TEQ) and 12 pg TEQ $g^{-1}$ fresh weight for the total-TEQ i.e. the sum of dioxins and dioxin-like PCBs (WHO-PCDD/F-PCB TEQ) in muscle meat of eel and products thereof (Directive 2002/69/EC). Half of the sampling sites in Belgium demonstrate DL-PCB levels exceeding the European consumption level (with a factor three on average). The levels of PCDD/FS and DL-PCBS measured in some sites gave rise to serious concern about the reproduction potential of the eels from these sites. Human consumption of eels, especially in these highly contaminated sites, seems unwise (Geeraerts *et al*., in press).

Trend analysis in a Belgian study (Maes *et al*., 2008) over the period 1994–2005 indicated that there were significant decreases in the average wet weight concentration of all PCB congeners, nearly all pesticides and four metals. The observed decline of PCBs in eel tissue was in agreement with other studies reporting on time-series of contaminants in fish. PCBs were banned from the EU in 1985 and since then, several time-series have indicated decreasing levels of contamination. Also concentrations of most pesticides decreased significantly over time. This was especially evident for $\alpha$-HCH and lindane, demonstrating that the ban of lindane in 2002 has positive effects on the accumulation in biota. Similar reductions were modelled for HCB, dieldrin and endrin; however these compounds were banned many years ago. Unexpectedly, concentrations of *p,p'*-DDT increased while at the same time, *p,p'*-DDD and *p,p'*-DDE demonstrated significant decreases.

The ratio of DDE over DDT was >1 in all eels analysed, normally suggesting that DDT had not been recently reapplied. At some locations in Flanders, however, the ratio of DDE over DDT rapidly decreased by an order of magnitude of three over a few years. Such a steep decrease, even if the ratio was higher than one, probably indicates recent application of DDT and demonstrates that not all stock was depleted. This urged regional policy-makers to make a serious attempt in order to collect the remaining stock of banned pesticides.

Some heavy metal concentrations decreased in the eel, in particular lead, arsenic, nickel and chromium were notably reduced. The concentration of lead in eel muscle tissue was consistently decreasing between 1994 and 2005, which possibly is related to the gradual changeover from leaded to unleaded fuels and a reduction of industrial emissions. For arsenic, nickel and chromium, the trend may be biased as data were available only since 2000. Cadmium and mercury, however, did not demonstrate decreasing trends and remain common environmental pollutants in the industrialized region of Flanders.

Following the very high levels of BFRs encountered in eels from Oudenaarde, new measurements were carried out in 2006 (Roosens *et al*., 2008). A descending trend in the contamination with BFRs was observed from 2000 to 2006 on this site. For PBDEs, levels have decreased by a factor 35 (26 500 to 780 ng $g^{-1}$ LW), whereas for hexabromocyclododecane (HBCD), the decrease was less conspicuous, (35 000 to 10 000 ng $g^{-1}$ LW). Based on these results we can conclude that in 2006, fish seem to be less exposed to PBDEs than 6 years earlier. This is probably as a consequence of the restriction regarding the use of the penta-BDE technical mixture (since 2004), a better environmental management and a raising awareness concerning PBDEs. However, since there are no restrictions regarding its usage, HBCD can still be detected in large quantities, especially in aquatic environmental samples taken next to industrialized areas, where it is used in specific applications. The textile industry is likely the cause of elevated BFR levels in fish on this part of the river Scheldt, but further studies should be set up to determine the exact origin and how far this contaminated area extends over the whole river.

It was concluded that Eel Pollution Monitoring Networks, such as the ones operated in Belgium and The Netherlands, allow getting a comprehensive overview of contaminants indicating environmental pressure, and they are able to document the temporal evolution of some of these pressures. These national monitoring networks should be upscaled at the European level. The intensity of pollution, at least at some sites, may well indicate potential negative effect on the health of these contaminated eels. These data underline the large variation in quality status of the eel over its distribution range. It is believed that this variation in quality is indicative with a variation in reproduction potential (Belpaire *et al.*, in press).

### 6.2.4 Contamination in eel and its role in the decline of the stock

We summarize the main findings of work in this field (see also Belpaire, 2008) in the following section and draw some conclusions related to the potential role of contamination in the collapse of the stock.

As a consequence of the increased international concern about the decline of the stocks, also research actions have paid increasing attention to analyse contaminants in the eel and to investigate the effects of these substances in the eel. As a result a large and growing quantity of information became available, and as suggested ICES 2007 a review on the effects of contaminants is underway. Many studies have examined the impact of a wide variety of xenobiotics on various aspects of fish biochemistry, physiology and population structure. In some cases of acute pollution, direct effects are clearly visible as fish may be moribund or dying. But contaminant exposure can lead to a decrease in growth or a lowered or deficient immunological system, causing an increased sensitivity to infectious diseases and parasites. But in most cases, these effects have been induced by effects on molecular and subcellular level. The last 20 years, an increasing number of reports deal with studying causality between pressure of xenobiotics and response at the subcellular level. In the eel, the impacts of contaminants on metabolic functions and on behaviour of the eel are widely divergent and act through various mechanisms. Figure 6.3 shows a simplified conceptual model of the effects of pollution exposure on the population structure of the European eel (after Geeraerts *et al.*, in prep, adapted from Lawrence and Elliott, 2003).

A significant negative correlation between heavy metal pollution load and condition was observed, suggesting an impact of pollution on the health of subadult eels (Maes *et al.*, 2005. In general, a reduced genetic variability was observed in strongly polluted eels, as well as a negative correlation between levels of bioaccumulation and allozymatic multi-locus heterozygosity (Maes *et al.*, 2005).

Van Campenhout *et al.*, 2008 studied the effect of metal exposure on the accumulation and cytosolic speciation of metals in livers of European eel by measuring metallothioneins (MT) induction. This research was carried out in four sampling sites in Flanders revealing different degrees of heavy metal contamination (Cd, Cu, Ni, Pb and Zn). It was concluded that the metals, rather than other stress factors, are the major factor determining MT induction. The effects of perfluorooctane sulfonic acids (PFOS) in Flemish eels were studied by Hoff *et al.*, 2005, indicating that PFOS induces liver damage.

In France, migrating silver eels *A. anguilla* were collected in a river system where algal blooms occurred yearly. Fifty per cent of eel livers were contaminated by microcystin-LR (the most common and toxigenic compounds associated with cyanobacterial blooms). Contaminated silver eels had lower fish condition compared to non-contaminated eels. Consequences of this impact for the breeding potential of these migrating eels are discussed, in particular the importance of lipids and energy reserve allocation. The consequences of contamination by microcystins on the breeding potential of silver eels should be further investigated (Acou *et al.*, 2008).

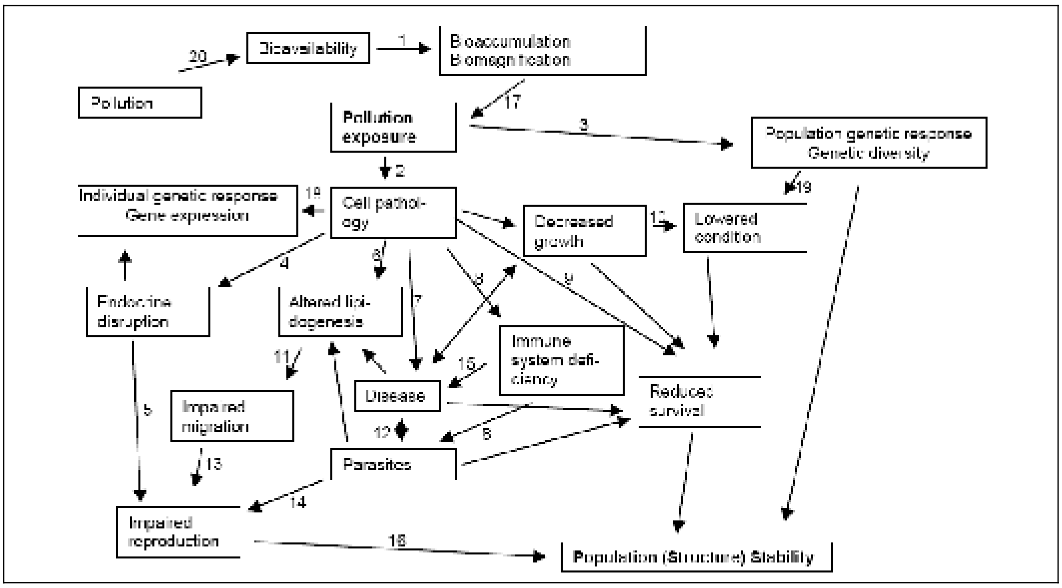


**Figure 6.3: A simplified conceptual model of the effects of pollution exposure on the population structure of the European eel, *A. anguilla*. Adapted from Lawrence and Elliott, 2003. Numbers refer to references: (1) Vollestad, 1992; (2) Tuurula and Soivio, 1982; Svobodova *et al.*, 1994; Azzalis *et al.*, 1995; Stohs and Bagghi, 1995; Sancho *et al.*, 1997; Ibuki and Goto, 2002; Pacheco and Santos, 2002; (3) Nigro *et al.*, 2002; Jha, 2004; Maes *et al.*, 2005; Nogueira *et al.*, 2006; (4) McKinney and Waller, 1994; Versonnen *et al.*, 2004; (5) Jobling *et al.*, 2002; (6) Jimenez and Burtis, 1989; Sancho *et al.*, 1998; Fernandez-Vega *et al.*, 1999; Robinet and Feunteun, 2002; Hu *et al.*, 2003; Pierron *et al.*, 2007; (7) Roche *et al.*, 2002; (8) Sures and Knopf, 2004; Sures, 2006; (9) Sancho *et al.*, 1997; (10) Gony, 1987; (11) Ceron *et al.*, 2003; van den Thillart *et al.*, 2005; (12) Van Ginneken *et al.*, 2005; (13) Johnson *et al.*, 1998; Palstra *et al.*, 2007; (14) Sures, 2006; (15) Van Ginneken *et al.*, 2005; (16) Corsi *et al.*, 2003; (17) Van Campenhout *et al.*, 2008; (18) Ahmad *et al.*, 2006; Maria *et al.*, 2006; (19) Jha, 2004; Maes *et al.*, 2005; (20) Belpaire *et al.*, 2003 (after Geeraerts *et al.*, 2008, in prep).**

Geeraerts *et al.*, 2007 analysed an extensive dataset of contaminants by statistical modelling and concluded that PCBs, especially the higher chlorinated ones, and DDTs, have a negative impact on lipid content of the eel. It was further demonstrated that fat stores and condition decreased significantly during the last 15 years in eels in Flanders and in The Netherlands (Belpaire *et al.*, 2008), jeopardizing a normal migration and successful reproduction. In Belgium and The Netherlands over the past 15 years, lipid contents dropped by about one-third (from ca. 20% to 13%) (Figure 6.4). Also the condition (Le Cren's relative condition factor) of the eels decreased. Lipid reserves are essential to cover energetic requirements for silver eel migration and reproduction. On the basis of the somatic energy reserves, reproductive potential of eels from various latitudes over Europe was estimated, assuming fat levels in yellow eel are indicative of those in silver eels. Only large individuals, females as well as males, with high lipid content seem to be able to contribute to the spawning stock (Belpaire *et al.*, 2008). Belpaire *et al.*, 2008 argue that the decrease in fat content in yellow eels may be a key element in the stock decline and raises serious concerns about the chances of the stock to recover (Figure 6.4).

It is therefore important to gain insight of the quality, lipid reserves and condition of the eels leaving continental waters and to include quality aspects in eel stock management. Both muscle lipid content and condition factor seem to be important integrative indicators in an overall estimate of the quality of the eels escaping to their spawning grounds.

Contaminant pressure is a plausible concern for the recovery of eel stocks and here we summarize arguments and hypotheses to underpin this:

1 ) Contamination has been demonstrated as the cause of population collapse of many other biota from the 1970s on (e.g. the collapse of several birds of prey in the 1960s as a consequence of DDT).

2 ) Many chemicals have been developed and put on the market, simultaneous with the intensification of agricultural and industrial activities during the 1970s. The timing of this increase in the production and release of chemicals may fit with the timing of the decrease in recruitment from 1980 on.

3 ) Eels bioaccumulate many chemicals to a high extent.

4 ) The more or less comparable decreases in recruitment in the Northern-hemisphere *Anguilla* species, like *A. rostrata* and *A. japonica*, during the last 30 years, might suggest that some new contaminants quickly spreading over the industrialized world, might have contributed to the decline.

5 ) Many reports have been dealing with direct adverse effects of contamination on individual, population and community level in fish. In eel, many detrimental effects of contaminants on the individual level have been demonstrated, including impact on cellular, tissue and organ level. Also genetic diversity seems to be lowered by pollution pressure.

6 ) Considering the high levels of contamination in eels from many areas, endocrine disruption in mature silver eels might be expected, jeopardizing normal reproduction. Dioxin-like contaminants have been reported to hamper normal larval development.

7 ) Lipid levels in eels have decreased considerably over the past 15 years. This decrease in lipid levels is mainly induced by contamination. Low lipid levels may have contributed to a reduction in migration and reproduction success.

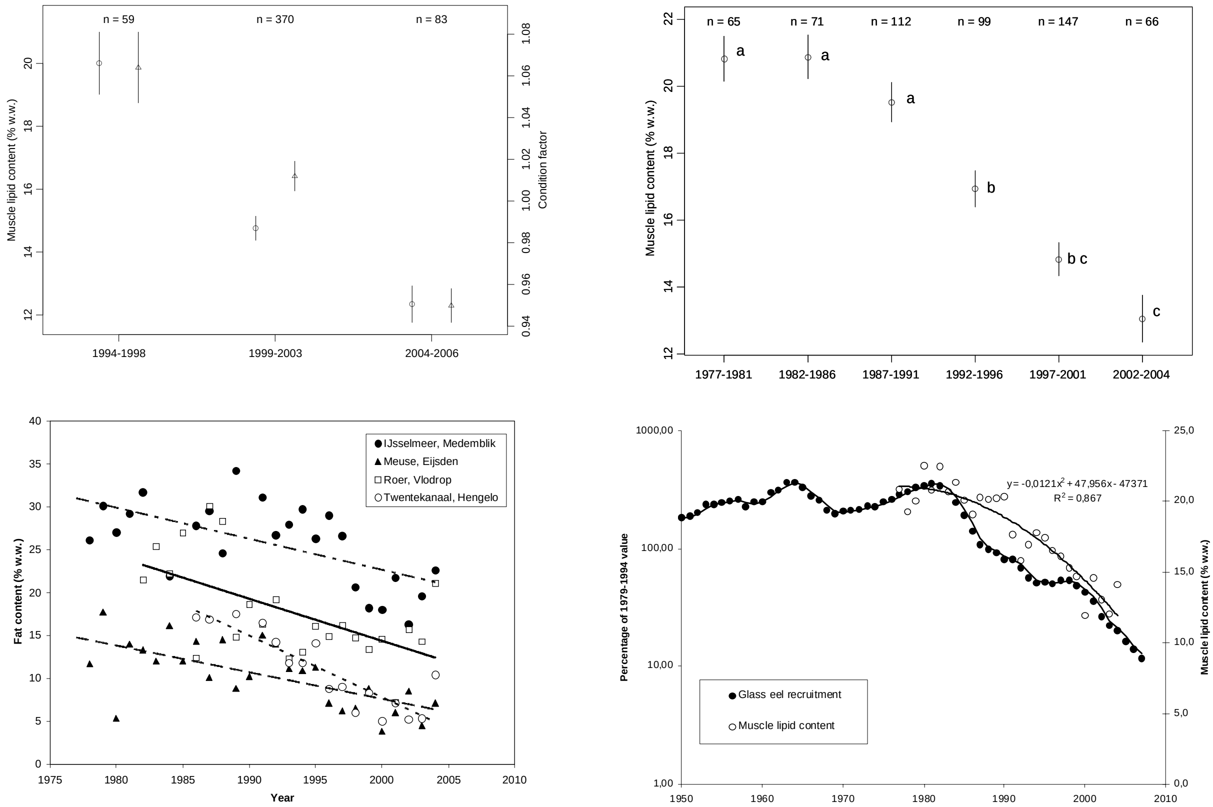


**Figure 6.4: Temporal trend in fat contents (% of wet muscle weight) of yellow eels in Belgium (upper left panel) and The Netherlands (upper right panel) (means, bars indicating standard errors). The number of sites is indicated. Means of periods with the same letter are not significantly different from each other. For the Belgian eels also condition factor is presented. Lower left panel: Temporal trends in fat contents in yellow eels from four water bodies of different typology. Time trend of the fat content in muscle tissue (pooled samples) from yellow eels in a lake (IJsselmeer), a large river (Meuse), a small river (Roer) and a canal (Twentekanaal) in The Netherlands. Lower right panel: Time-series of glass eel recruitment in Europe (ICES 2007) and of muscle lipid contents in yellow eels from The Netherlands. Data of the time-series of glass eel recruitment are geometric means of monitoring data of recruiting biomasses in 21 European rivers, each series being scaled to its 1979–1994 average. Data of muscle lipid contents are means of pooled yellow eel samples from The Netherlands between 1977 and 2004 (Belpaire *et al.*, 2008).**

**Note: in the lower right panel: recruitment is on a log scale and muscle lipid is on a normal scale.**

## 6.3 Parasites/pathogens

*A. crassus* can be considered widespread throughout Europe and there is a growing evidence that *A. crassus* is spreading further into new areas. New data in 2008 indicated the presence of the nematode in Canada (not included in the EEQD yet) for the first time. Further process research is required before the impact of contaminants and parasites can be included in the quantitative stock assessments.

## 6.4 Quality assessment of spawners using genomic tools

Eel decline might depend not only on the quantity of adult eels leaving the continent, but also upon their quality. Good quality spawners are those that succeed in crossing the Atlantic Ocean and reproduce. Parasites, such as the exotic swimbladder nematode *A. crassus* can impair eel viability by both increasing continental mortality and affecting the swimming ability of adult eels. Organic and inorganic pollutants may significantly reduce the quality and reproductive capacity of vertebrates. This is especially the case in fish, where pollutants may accumulate in the water and sediment and in the benthic biota (food). Additionally, infections and pollution have been revealed to impair strongly the survival and reproductive capacity of eels in experimental trials, resulting in an even stronger response to pollution and vice-versa (Palstra *et al.*, 2006; 2007). A thorough analysis of pollutants and pathogen stress levels and a better understanding of the biological response (besides measures of condition index) are missing. Pujolar *et al*., 2005 and Maes *et al*., 2005 assessed whether the genetic background of European eels could be linked to two fitness traits, early growth and pollutant bioaccumulation. Summarizing both studies here, there was strong evidence of a relation between genetic diversity and fitness measures (also called Heterozygosity-Fitness-Correlations or HFCs). It might be explained either by an effect of direct overdominance at functional markers. Recently, it became possible to reliably quantify the gene and protein expression levels during exposure to pollutants and parasites, allowing the early detection of decreased fitness and survival. Such knowledge would provide the chance for early warning systems, facilitating management actions before major mortality events in natural populations and provide a long-term assessment of success rates of conservation measures. Using sufficient background information on the identity and concentration of pollutant, this approach may yield better insights into the factors influencing the recently observed decrease in fat content, a potentially crucial measure for eel's ability to reach the Sargasso Sea. The ongoing analyses of northern (Belgium) and Southern (Italy) eel populations for their gene expression level and health status will allow adding a quality status tag on silver eels, while identifying good quality habitat for preservation.

## 6.5 The European Eel Quality Database

### 6.5.1 Introduction

In 2006 the EEL WG recommended that further sampling and ongoing monitoring into eel quality was urgently required. Member countries should set up a national programme on RBD scale to evaluate the quality of emigrating spawners. This should include at least body burden of PCBs, BFRs, infestation levels with *A. crassus*, and EVEX. It should be included in the national management plans while special emphasis should be given to standardization and harmonization of results (units and methods). To this effect the European Eel Quality Database was created in Belgium in 2007 and circulated among members of the EELWG requesting data on fat composition, contaminant analysis and infection parameters of *A. crassus.* During the intersession period and during the Working Group meeting 2008 eel quality data has been provided and included in the EEQD.

The database is coordinated by the Research Institute for Nature and Forest (Belgium) and includes data on eel quality elements, such as condition, contaminant concentrations and epidemiological parameters, in addition to the relevant descriptors of date and place of sampling and sample characteristics (eel life stage, number and morphometrics). The database was initially restricted to a limited number of quality elements (lipid content, ca. 30 chemicals and *A. crassus* infection parameters). During WGEEL 2007 some countries reported on some more elements, and the list of ICES7 (CB28, CB52, CB101, CB118, CB138, CB153 and CB180) congeners was extended with non-*ortho* and mono-*ortho* congeners, as they exhibit the highest dioxin-like toxicity and contribute most to the TEQ (toxic equivalency). Also one pesticide, several metals and some bacterial disease agents were added.

During the WGEEL, 2008 evidence has been presented that condition factors are important elements for estimating eel quality (Acou *et al.*, 2008; Belpaire *et al.*, 2008). It was recommended that condition should be included in the EEQD, this requires however a standardized methodology (Froese, 2006).

### 6.5.2 Analysis of the EEQD

During the Working Group session, new data were compiled and the EEQD now contains information from 14 countries reviewed in Table 6.2. Data from Norway, France and Estonia also are available and will be included in 2008. Data source is heterogeneous, data deriving most from national or local level surveys, but also from eco-toxicological studies. Belgium has presented the most exhaustive information, as a consequence of the availability of data from the Flemish eel pollution network, in place since 1994 (Belpaire and Goemans, 2007). Norway also provided a long time monitoring series in the Grenland fjords (S. Norway) following the discovery of PCDF/PCDDs in edible organisms after a 99% reduction in the load of waste components from the Hydro Porsgrunn magnesium factory (Knutzen *et al*., 2001). However, the longest dataseries for bioaccumulation of contaminants is from the Netherlands, because in this country a monitoring network for PCBs, OCPS and mercury in eel is in place since the 1979s, linked to the safety for consumption norms. Germany and UK have provided data on concentration of pollutants and contaminants relative to some river basins, carried out within local monitoring programmes. Some countries (Italy, Portugal, Spain) did report data drawn from eco-toxicological studies carried out within specific researches. Some countries (e.g. France and the Netherlands) have published reports demonstrating that considerable information is available. At the present moment this information is not accessible for inclusion in the EEQD. On the whole, eel quality data were provided for approximately 600 different sites over Europe; at the present however, the database is overbalanced, most of the sites being situated in Belgium. Most information is available for heavy metals (771 records), PCBs (695 records) and organochlorine pesticides (OCPs) (656 records) while 566 observations on lipid content were also included. Apart from some observations on bacterial diseases available for three sites in Spain and one site in UK, disease agents included in the database are restricted to the swimbladder nematode *A. crassus*, with epidemiological data from 335 sites across Europe.

Given the importance of lipid levels as an energy resource utilized during the eels' migration and for the production of gametes, disturbing data are seen in Europe. Four out of twelve countries have a fat percentage above 20% (Figure 6.5, the minimal lipid storage needed for a successful reproduction (Boëtius and Boëtius, 1980; Van den Thillart *et al*., 2004; 2005).

Research on the fat content in yellow eels has been done on two (independent) large datasets of lipid contents in yellow eels from Belgium and the Netherlands. A 7.7%

decrease in lipid content on wet weight basis over a 13 year period has been revealed in Belgium. Whereas in the Netherlands before 1990 the mean fat content was generally superior to 20%, a clear and significant decrease occurred after 1990. Notwithstanding the differences in both network concepts, and large variation in lipid contents of eels from various water bodies, similar trends were obvious in Belgium and the Netherlands: a drop in lipid contents over the past 15 years by about one-third (from ca. 20% to 13%) (Belpaire *et al*., in press).

**Table 6.2: Overview of the number of records of eel quality data compiled during the WGEEL 2008 and incorporated in the European Eel Quality Database.**

| Country | Fat | PCB | Pesticides | Heavy metals | A. crassus | BFR | Dioxin | PFOS |
|---|---|---|---|---|---|---|---|---|
| Belgium | 409 | 408 | 373 | 373 | 140 | 24 | 8 | |
| Denmark | 7 | 6 | 6 | | 3 | 4 | | 12 |
| Estonia | | | | | | | | |
| Finland | | | | | | | | |
| France | | 12 | | 3 | | | | |
| Germany | 14 | 12 | 23 | 23 | 26 | | 2 | |
| Ireland | 13 | 9 | 7 | | 6 | 7 | 7 | |
| Italy | 24 | 24 | 20 | 7 | 10 | | | |
| Latvia | | | | | | | | |
| Lithuania | | | | | | | | |
| Northern Ireland | 2 | | | | 3 | | | |
| Norway | 8 | 8 | 8 | | | | | |
| Poland | 7 | 7 | 7 | 7 | 21 | | 7 | |
| Portugal | 1 | 1 | | 12 | 8 | | | |
| Spain | 18 | 60 | 73 | 52 | 52 | | | |
| Sweden | 25 | 10 | 1 | 179 | 51 | | 7 | |
| The Netherlands | 37 | 99 | 99 | 76 | | | | |
| UK | 1 | 39 | 39 | 39 | 16 | | | |
| TOTAL | 566 | 695 | 656 | 771 | 335 | 35 | 31 | 12 |

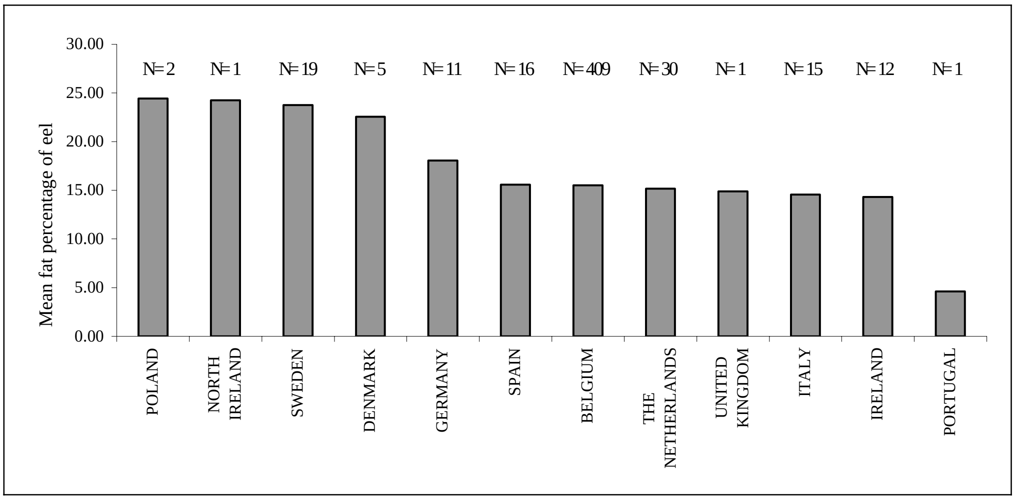


**Figure 6.5: Variations in mean muscle lipid content (%) in yellow end silver eels in Europe. N indicates the number of sites on which the mean values are calculated.**

### 6.5.3 Future development of the database

The development of a European Eel Quality Database in the WGEEL 2007 has been updated during the 2008 session and now forms the basis for compiling a comprehensive pan-European overview of eel quality data.

There is a wide range of information widely scattered over Europe by location and collecting agency. The collection and reporting of eel quality data are recommended within the international framework for the restoration of the species (Data Collection Regulation) as proposed by the Working Group on Eel (ICES, 2006) and the Scientific, Technical and Economic Committee for Fisheries of the EC (STECF, 2006). The collection of such data are now also included in the guidelines for the preparation of Eel Management Plans.

Some information is missing and the database has to be expanded and further updated in the future. For instance some countries (e.g. France and the Netherlands) have published reports that demonstrate considerable information is available but data were not presented for inclusion in the EEQD. It is also presumed that many unpublished results are available in some countries and should be utilized by inclusion in the database. Some were provided during the Working Group meeting, but could not be included in the database at the time.

Considering that eel quality could be a major element in the decline of the species, the database may become a useful tool for the (inter)national eel conservation measures. The database allows the identification and designation of good quality sites where special measures for maximum protection of stocks and emigrating spawners of good quality can be proposed (e.g. restriction of fisheries, priority places for restocking, priority for habitat restoration measures, etc). From preliminary analyses it was clear that many contaminants and lipid reserves varied a lot over the distribution area of the eel (ICES, 2007) and the presence of 'black spots' was identified. EEQD data on disease agents such as *A. crassus* demonstrated a widespread distribution over Europe. From an environmental point of view it is clear that the database will give information about specific environmental chemical pressures and will indicate pollution areas for specific contaminants. The database will allow an overview and in-depth analysis of eel quality on a Europe wide scale and follow-up of emerging problems of a chemical or epidemiological nature and could also be used as an early warning system for the spread of new eel diseases or contaminants. Yellow eels have been proposed as a sentinel organism for evaluating the chemical quality of priority hazardous substances in biota in accordance with the WFD. EEQD can integrate these data and make them available for eel stock management. The database will pinpoint sites where the quality of eels is below that deemed suitable for human consumption, so adequate fisheries management measures, like closing fisheries or preventing consumption of eels, can be taken in these areas.

## 6.6 Conclusions and recommendations for Chapter 6: Eel quality

### 6.6.1 Conclusions

Estimation of effective spawner biomass requires quantification of the adverse effects of contaminants, parasites, diseases, low fat levels, non-lethal turbine damage, along the lines previously proposed for *A. crassus*, as well as other mortality rates throughout the river basin. Present knowledge does not fully permit quantitative assessment of the effects of these factors on the overall stock.

The European Eel Quality Database (EEQD) has been updated with data on contaminants, parasites and fat levels in eel, allowing the compilation of a comprehensive overview of the contaminant load in eel over its distribution area. Results demonstrate highly variable data within river basin districts, according to local anthropogenic pollution, linked with land use. Persistently elevated contamination levels, above human consumption standards, are seen in many European countries. The most important reported impact is seen on the fat content of the yellow eels (i.e. in Belgium and the Netherlands) which has decreased over the last number years and which raises concern regarding the migratory and reproductory success of silver eels. There is growing evidence that *A. crassus* is spreading further into new areas and new data indicate the presence of the nematode in Canada (not included in the EEQD yet) for the first time.

Clear ecotoxicological effects of contaminants have been demonstrated. The most important impact is seen on the fat content of the eels which is decreasing over the last number of years and which may jeopardize migration and reproduction success.

The value of monitoring contaminants in eel for environmental issues has been demonstrated. But the eel as a bio-indicator is not recorded in the Water Framework Directive and the number of contaminants recorded is insufficient for safeguarding sufficient eel health.

### 6.6.2 Recommendations

The Working Group recommends the continuation on a local scale of the long-term monitoring of quality (contaminants, parasites and disease) in eel with an emphasis on standardizing the methodological approach, analysis of new compounds, an appropriate communication system and robust data management. The European Eel Quality Database should be developed and maintained. Member States should initiate harmonized monitoring strategies aimed toward the development of a European Eel Quality Monitoring Network, to collect the relevant data to be fed into the EEQD.

The Working Group recommends investigations into eel quality of the eels leaving continental waters so as to include quality aspects in eel stock management and evaluation of effective spawning escapement.

Carry out a Europe wide study to comprehend relationships between contamination and eel stock decline. An important focus should be to study the effects of contaminants on lipid metabolism and condition.

The Working Group repeats its recommendation that contaminant monitoring in eel should be included as a tool for measuring the chemical status of our water bodies as defined in the Water Framework Directive.

# 7 Oceans, climate and recruitment

## 7.1 Introduction

Term of Reference c. tasked the Working Group to, "review hypotheses and information on the possible relationships between the European (and American) eel stock(s), recruitment patterns and climatic and oceanic factors".

European *A. anguilla* and north American *A. rostrata* eel spawn in the Sargasso Sea. This part of the life cycle has not been witnessed or quantified and therefore the full stock–recruitment relationship circle cannot be closed at present. Oceanic factors, biological and physical, may influence the recruitment of eel through impacting on both the migrating silver eels and on the subsequent return of juvenile recruits. Overlaid on this, recruitment of European eel has decreased by approximately 95% since 1982 (Dekker, 2003) and is below 5% since 2000 (ICES, 2007).

In addressing this ToR, the WG in its pre-meeting undertook a literature review and invited submissions to this review. The WG would like to acknowledge inputs from Beaulaton, Bonhommeau, Cairns, Dekker, Friedland, Kettle, Knights, and Miller.

## 7.2 Review of ocean change/controlling mechanisms

Long-term climate variation in the North Atlantic has been revealed to correlate with observed trends in aquatic and terrestrial ecosystems throughout Europe (Ottersen *et al.*, 2001). SST (sea surface temperature) differences may be the main drivers of the North Atlantic Oscillation (NAO) and associated continental climate change. Cycles of change could result from slow transfers of warmer/colder water by the major thermohaline and wind-driven gyre currents (Hurrell, 1995). Changes in the NAO winter index (NAOI) since the 1820s appear to follow cycles with periods varying in the range 7 to 13 years. In addition to the NAO there are other natural longer period climate cycles i.e. the approximately 60 year Atlantic Multidecadal Oscillation (AMO, Sutton and Hodson, 2005) (Figure 7.1). Superposed on the natural climate oscillation is the steady anthropogenic increase of global temperature.

The widely used NAO index quantifies alterations in atmospheric pressure between the subtropical Atlantic (Azores) and the Arctic (Iceland). An increased Azores High indicates more and stronger winter storms crossing the Atlantic in a more northerly track, and shifts the Gulf Stream to a more northerly position. A number of alternative indices have been defined, varying in the months included, the analysis procedure and the exact locations measured (Dekker, 2004a). The NAO winter index is always used, because it provides the most pronounced signal. The North Atlantic SST demonstrates a long-time downward trend expressing the combined effects of NAO and AMO from the early 1940s until the early 1970s followed by a gradual increase until the mid 2000s, amplified by the anthropogenic warming. The most recent data indicate the beginning of a cooling period. The unusual warming of the North Atlantic is also indicated by the relationships to the Sargasso Sea Surface Temperature (SS-SST) (Figure 7.2). Other parameters have also been analysed by various authors and their putative effects are described in Table 7.1.

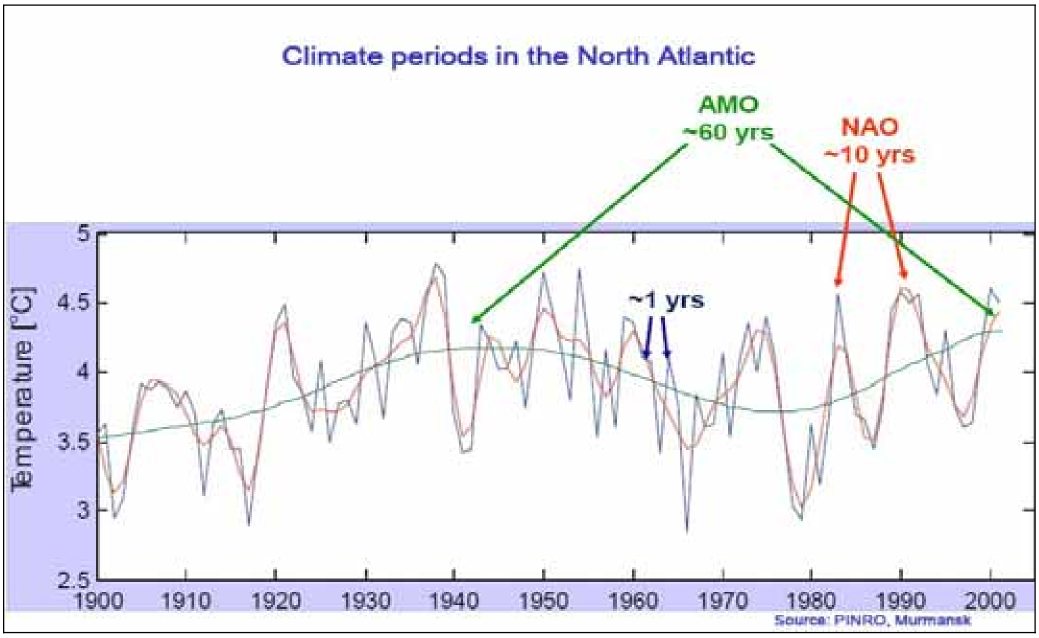


**Figure 7.1: The effect of the natural climate oscillations over the North Atlantic area on the mean yearly sea temperature of the Kola section in the Barents Sea illustrating the interaction between decadal and multidecadal time-scales. From Svein Sundby presented at *Fisheries Management and Climate Change in the Northeast Atlantic Ocean and the Baltic Sea,* Bergen 17–18 April 2008.**

## 7.3 Review of recruitment patterns in eels

Leptocephali larvae of European eel are transported along the Gulf Stream and North-Atlantic Drift for a journey taking somewhere between an estimated 8–9 months (Lecomte-Finiger, 1992) and 2–3 years (Tesch, 2003; Kettle and Haines, 2006; Bonhommeau *et al.*, 2008) to arrive back to the eastern Atlantic coast where they metamorphose to glass eels, ascend rivers and grow as yellow eels until reaching partial maturity (Tesch, 2003). American eel leptocephali must also reach the Florida Current or Gulf Stream, although they later have to leave that current system to recruit to the coast of North America. Leptocephali grow larger and have a longer larval duration than most fish species, taking up to a year or longer before they recruit to fresh-water habitats as glass eels or elvers. This long larval duration is thought to make leptocephali particularly susceptible to changes in ocean currents and food availability (Friedland *et al.*, 2007).

A fundamental question in resolving the role of ocean circulation in life cycle of the European eel is the duration of the larval migration. Schmidt, 1923 made a careful analysis of the age cohort size structure for leptocephali captures across the Atlantic Ocean and concluded that the passive transatlantic migration lasts two years with the metamorphosed glass eels entering fresh and brackish waters in spring at the end of their third year. Direct Lagrangian simulations (Harden Jones, 1968) indicated that the migration should take 2.5–3 years. A more recent Lagrangian study (Kettle and Haines, 2006) suggested that the duration of the larval eel migration was probably about two years. On the other hand, glass eel otolith ring counts have indicated an oceanic migration time of less than a year (Lecomte-Finiger, 1992), but there is debate about whether the growth rings are deposited daily. Knights, 2003 and Friedland *et al.*, 2007 suggest that there may only be a one year time delay oceanic perturbations represented by the NAO and the DenOever glass eel index, implying a one year migration period. The most recent study by Bonhommeau *et al.*, 2008 has indicated that there is a 2–3 year time-lag between perturbations of ocean temperature and primary productivity in the Sargasso Sea and glass eel recruitment indices in Atlantic France, and there is a convergence of opinion that the duration of the larval migration may be approximately two years.

**Table 7.1. Oceanic parameters that have been analysed by various authors and their putative effects on eels.**

| Oceanic factor | Mechanism of influence | Author |
|---|---|---|
| North Atlantic oscillation NAO | NAO quantifies the alteration in atmospheric temperatures between the Azores and Iceland.<br>It indicates a more northerly position of the Gulf Stream. Impacts larval migration | Dekker, 2004 |
| Sargasso Sea Sea Surface Temperatures<br>(SS-SST), average 0-100 m deep | The marine production increases with sea surface temperature in the cooler waters from the North Atlantic but decrease in warmer waters. This effect is as a consequence of a reduced vertical mixing and lower marine production thus impacting larval feeding | Bonhommeau *et al.*, 2008 |
| Sargasso Sea Winds | Surface current, caused by the combined effect of wind and Coriolis forces, have diminished, reducing the westward transport towards the Florida current into the Gulf Stream–could affect transport of leptocephali | Friedland *et al.*, 2007 |
| Mean Temperature of the northern hemisphere<br>(NHT) | Would reflect climate change and its impact on primary production in the ocean and larval feeding. | Knights and Bonhommeau, unpublished |
| Gulf Stream Index (GSI) | Latitude of the Gulf Stream, from monthly charts of the north wall | Bonhommeau, 2008 |
| Transport index (TI) | Strength of the Gulf Stream and North Atlantic current system (baroclinic gyre circulation in the North Atlantic)<br>Calculated from potential energy anomalies (PEA) between Bermuda and Labrador basin – could affect transport of leptocephali | Bonhommeau, 2008 |
| PP (Bermuda biological station, North of spawning area) | Primary production. Considered as a good proxy for leptocephali food. | Bonhommeau, 2008 |
| Sea surface temperatures anomalies (SSTA) | Food availability for leptocephali would be expected to be reduced during warm high SSTA periods as a consequence of reduced spring mixing, nutrient recirculation and productivity | Knights, 2003 |
| Surface expression of the 22.5°C isotherm | The 22.5 °C isotherm is a useful indicator of the northern limit of spawning by both species of eels in the Atlantic.<br>Therefore, changes in the latitude or intensity of these fronts may affect both the spawning location and the subsequent transport of the leptocephali to continental habitats. | Friedland *et al.*, 2007 |

A very short time-lag compared to the drift estimates seems unlikely considering the swimming ability of the leptocephalus larvae (Bonhommeau, 2008). To gain one year in the transatlantic migration the larvae has to sustain a continuous, directed swimming velocity of 15 to 20 cm/sec, or 3–5 body-lengths/sec. A typical anguilliform swimming speed is of the order 0.5 body-lengths/sec (Ellerby *et al.*, 2001).

Meta-analyses of many local dataseries have revealed common trends in the population. The breakpoint in the recruitment series in south and middle Europe from 1980 points to a shared process causing the decline thereafter. Recruitment series of young yellow eel in northern Europe deviates from this, with an earlier decline starting during the 1950s. This could be interpreted as a different climatic effect on the north- and south- going branches of the North Atlantic drift, which splits into the North East Atlantic and the Canary currents to the southwest of Ireland.

## 7.4 Review of hypotheses of causal linkages between oceanic factors and recruitment patterns

The mechanism or mechanisms behind the observed correlation between glass eel recruitment and climate oscillations are unknown. The migratory phase of adults and larvae, as well as the egg and larvae production might have been influenced by climate variation. Currently it is difficult to separate out the impact of ocean and climate on spawner migrations and on subsequent migrations of larvae and recruiting glass eels.

It has long been recognized that there may be a direct link between larval migration success and the density, or thermohaline circulation, of the ocean. The NAO might impact the larval migration by changing the ocean currents or by influencing ocean productivity and food availability for the migrating larvae (Knights, 2003). The long-term variations in glass eel recruitment indices may be modulated by characteristic time-scale of the NAO index, which varies in periodicity between 7 and 13 years. This had important implications in explaining the long-term decline in glass eel recruitment across Europe since the late 1970s as it has been recognized that the NAO index had been in a prolonged positive phase over this period (ICES, 2001; Friedland, 2007).

Focussing on the long term DenOever glass eel index, Friedland *et al.*, 2007 established the existence of significant correlations with environmental parameters in the North Atlantic during the spawning period between February and May: the surface expression of the 22.5°C isotherm, the eastward windspeeds, and the NAO. Explanations for the observed relationships focused on the possible influence of wind-induced geostrophic transport in advecting larvae into the Gulf Stream and on the impact of interannual variability of the mixed layer depth on nutrient supply and ocean productivity in providing food to the developing larvae.

A close negative relationship has been found over the last four decades between long-term fluctuations in recruitment and in sea temperature (Table 7.2). By contrast, variations in integrative indices measuring ocean circulation, i.e. latitude and strength of the Gulf Stream, did not seem to explain variations in glass eel recruitment (Bonhommeau *et al.*, 2008).

The impact of food availability in the Sargasso Sea on the success of the larval eel migration was suggested and rejected by Desaunay and Guerault, 1997. Using information about the length of the oceanic migration from otoliths the conclusion was that the number and physical condition of glass eels arriving on the coast of France was linked to chlorophyll concentration and food availability in the Sargasso Sea at the time of spawning. The largest glass eels near the spring arrival peak in coastal France were assumed to have started in the Sargasso Sea during the spring chlorophyll bloom of the previous year.

Bonhommeau *et al.*, 2008 used a short time-series to demonstrate a correlation between recruitment and primary production in the Sargasso Sea demonstrating a strong bottom–up control of leptocephali survival and growth. On a longer timescale, SST is used as a proxy for primary production and related to recruitment indices. Sea warming in the eel spawning area since the early 1980s may have modified marine production and eventually affected the survival rate of European eels at early life stages (see Figure 7.2). Direct measurements of primary productivity in the northern Sargasso Sea were also found to be correlated with a three-year lag to the Loire River recruitment time-series in France, but not those at the other locations (Bonhommeau *et al.*, 2008). Changes in ocean productivity may also be associated with changes in the length and condition of glass eels recruiting to Europe (Desaunay and Guerault, 1997**;** Dekker 1998; 2004b).

Kettle *et al.*, 2008 have demonstrated that the NAO repeat cycle is present both in the glass eel catches and the FAO eel landing statistics. This means that there may be a resonant amplification between silver eel escapement and glass-eel recruitment. All stages of the life cycle appear to respond to interannual climate variability associated with the NAO, but it is not clear if the larval migration success is impacted directly by meteorological conditions over the Sargasso Sea or if it is modulated by the number of silver eels that are triggered to spawn by NAO-associated rainfall patterns in Europe.

**Table 7.2: Correlations between various glass eel recruitment series and oceanic parameters.**

| Recruitment series | Oceanic parameter | Correlation | Time Lag (years) | Author |
|---|---|---|---|---|
| | | **Transport related parameter** | | |
| Series from Loire, L'Ems & Den Oever, 1950–2001 | NAO (winter index) | -0.13 | 0 (max 1 and 6 years) | Dekker, 2004 |
| DenOever 1938–2005 | NAO (winter index) | -0.35 | 0 (max 0 and 8) | Friedland *et al.*, 2007 |
| 10 series | NAO (winter index) | GAM model significant effect but no linear trend | | Beaulaton, 2008 |
| 26 series | NAO (winter index) | Anticorrelated-significant | 1 to 4 | Kettle *et al.*, 2008 |
| Drakkar model, particles that succeeding in reaching the 20 W | NAO (winter index)<br>GSI<br>PEA | 0.5<br>0.73<br>0.57 | 0 | Bonhommeau, 2008 |
| Mercator model, particles succeeding in reaching the 20 W | NAO (winter index)<br>GSI<br>TI | 0.78<br>0.80<br>0.47 | 0 | Bonhommeau, 2008 |
| Drakkar model, minimum migration duration | NAO (winter index)<br>GSI<br>TI | -0.57<br>-0.75<br>-0.48 | 0 | Bonhommeau, 2008 |
| 21 series<br>1935–2007 | NAO | -0.28<br>-0.31<br>-0.35 | 2<br>3<br>7 | Knights and Bonhommeau, unpublished |
| 7 series | TI | NS | 3 | Bonhommeau *et al.*, 2008 |

| Recruitment series | Oceanic parameter | Correlation | Time Lag (years) | Author |
|---|---|---|---|---|
| 7 series | GSI | NS | 3 | Bonhommeau *et al.,* 2008 |
| DenOever 1947–2004 | Latitude of the surface expression of the 22.5°C isotherm in the Sargasso Sea | -0.15 to -0.39 according to month and longitude | 1 | Friedland *et al*., 2007 |
| DenOever 1949–2003 | Winds | -0.09 to -0.48 | 1 year | Friedland et al., 2007 |
| | | **Production related parameters** | | |
| 1955–2007 | SS-SST | NS | 1–6 years | Knights and Bonhommeau, unpublished |
| 1935–2007 | NHT | NS | 2–3 years | Knights and Bonhommeau, unpublished |
| Loire series from trader 1994–2004 | PP | 0.74 | 2.5 years | Bonhommeau *et al*., 2008 |
| Ems DenOever, Loire Nalon 1960–2005 | SS-SST | -0.88 | 2.5-year | Bonhommeau, 2008 |
| DenOever (3 year average) 1952–1995 | SST anomaly at 100–250 m | -0.47<br>-0.30 | 0 year<br>1 year | Knight, 2003 |
| DenOever (1960–1996) | Size of glass eels | 0.7 | 0 year | (Dekker, 1998) |

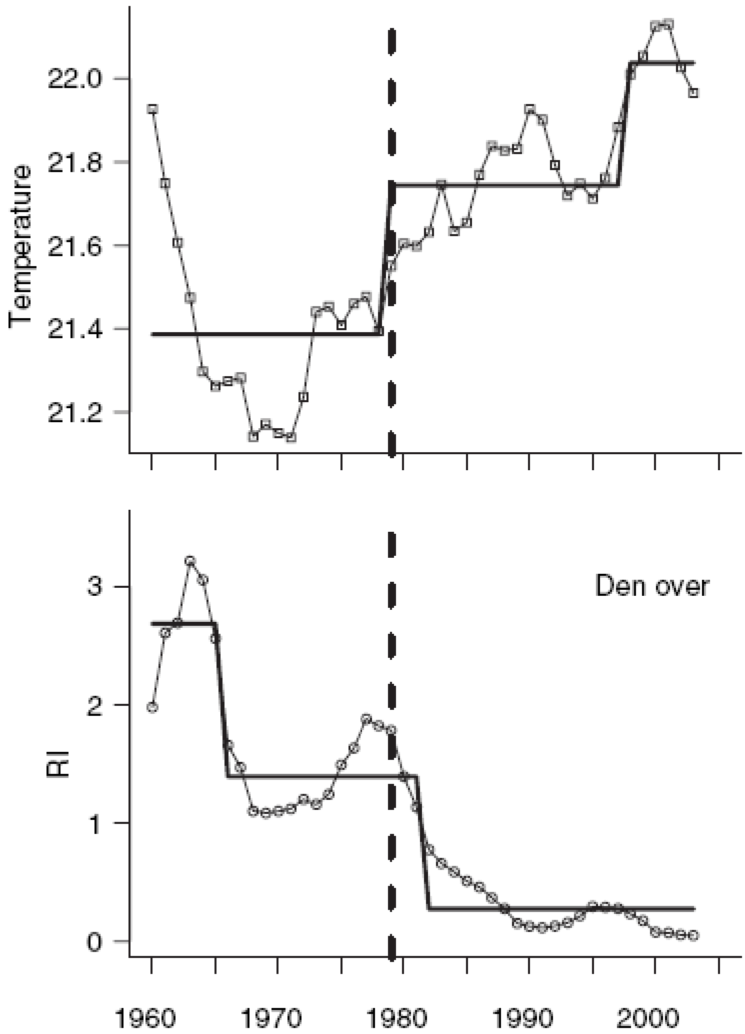


**Figure 7.2: Time series of DenOever recruitment index (5-yr moving average; solid line with circles) and temperature (°C; 5-yr moving average; solid line with squares) in the Sargasso Sea from 1960 to 2003. Bold lines indicate regime shift detection (Rodionov and Overland, 2005) and vertical dashed line indicates the regime shift in temperature in 1979. (Reproduced from Bonhommeau *et al.*, 2008).**

## 7.5 Ocean factors as reason (or contributory factor) for recruitment decline (1980s onwards)

The historic record shows strong evidence that the abundance and size of glass eels recruiting to the continent have the same periodicity as natural climate oscillations (Figure 7.3). Evidently NAO, and other climate cycles, are primarily meteorological indices that, at most, can be proxies to those ecological and hydrographic changes in the North Atlantic that could be the primary causes for variations of eel recruitment. Several parameters are possible candidates for the cause of the decline e.g. sea surface temperature anomalies and changes in productivity linked to temperature.

A shift in sea temperature in 1979 marked the beginning of changes in the Sargasso Sea environment and was followed by the large shift in eel recruitment detected in 1982 in most of the European rivers that have been analysed (Bonhommeau *et al.*, 2008). Correlation analysis of the glass eel catches revealed that almost all the monitoring indices across Europe vary in phase, providing support that they are modulated by a large-scale meteorological disturbance (i.e. as previously suggested by Knights 2003; Friedland *et al.*, 2007). However, measuring ascending young eels (young of the year, and older), the drop in recruitment in northern European rivers was observed considerably earlier. This leaves the possibility open that conditions closer to the European shelf may be important or that the decline in southern Europe started earlier also (see l'Adour and Gironde series, Chapter 2).

Temperature may be one of the main governing factors influencing eel larvae survival by decreasing food availability in the Sargasso Sea (Bonhommeau *et al.*, 2008). The size of glass eels is positively correlated with abundance and with the NAO-cycle. This also points to a role of ocean primary production on the feeding of glass eel and possible starvation of leptocephali. (Dekker, in prep, Figure 7.3).

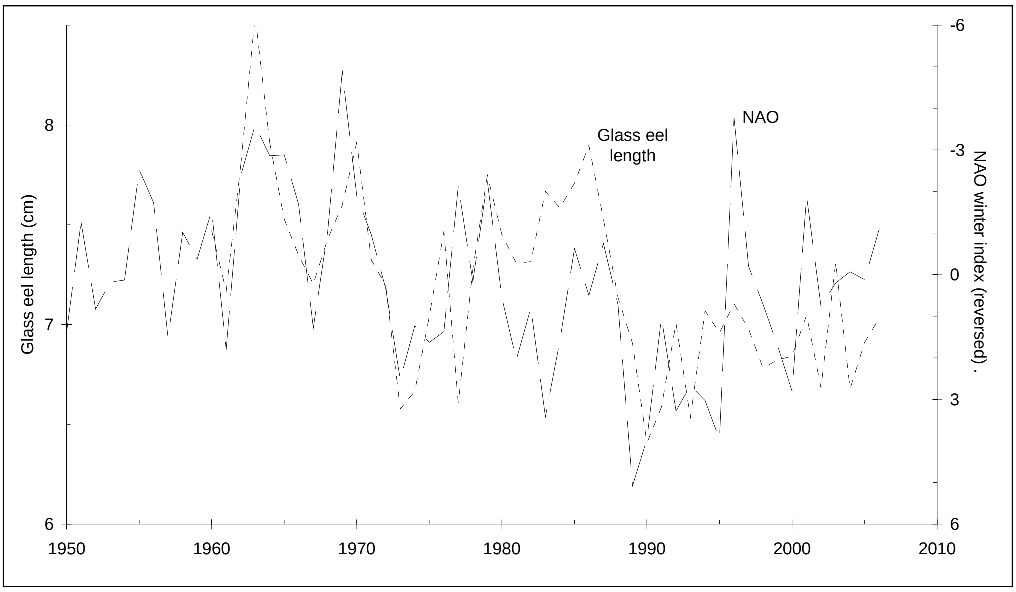


**Figure 7.3: Trends in glass-eel length entering Lake IJsselmeer (short dash), and the NAO winter index (long dash). (Data from Dekker, 1998 and Hurrell, 1995). (From Dekker, in prep).**

Changes in ocean currents, particularly in the Sargasso area, may have also affected glass eel recruitment. This assertion is supported by the correlation between recruitment series and NAO. It is also supported by results from modelling demonstrating the positive effect of transport indices on both success and time of migration. However, when looking at indices related to the strength of the Gulf Stream (TI and GSI), no significant correlation was found (Bonhommeau, 2008).

The steep decline in recruitment between 1980 and 1983 and the continued low and still declining recruitment since then cannot be easily explained by oceanic factors alone. The demonstration of a possible stock recruitment relationship (Dekker, 2003; 2004b; updated by WGEEL 2007) demonstrates strong evidence of a depensatory mechanism in the relationship. In this S/R relationship, landings have been used as a proxy for continental stock and it is assumed that continental stock varies in parallel with SSB. It is possible that this relationship between stock and SSB is not constant and that SSB has declined faster than the stock, possibly as a consequence of a breakdown in the migratory phase, the spawning process and/or the quality of the spawners, leading to a smaller number of recruits per spawner than observed prior to the 1980s. Isolation or fragmentation of spawning effort as a consequence of low SSB may have exacerbated this. The steep stock related decline in recruitment could be overlaid on the oceanic influences and might have drowned out the ocean signals in latter years.

A different view to this is proposed by Knights and Bonhommeau, unpublished. They found that combined and geographical-area stock trends are more meaningful than landings data for use in formulating stock–recruitment hypotheses and modelling and in developing management targets. Their results predict that glass eel recruitment would to be able to recover in less than 10 years from very low levels if ocean-climate conditions become more favourable. This conflicts with the life cycle modelling study of Astrom and Dekker, 2007 which concluded that stock recoveries could take >80 years. Also, Dekker *et al.*, 2003 and Dekker, 2004b assumed the general decline in combined landings was a proxy for stocks and hence spawning stock and that depensation could have led to the falls in recruitment 20 years later. The study by Knights and Bonhommeau, unpubl. however, suggests that fluctuations in environmental factors, both oceanic and near-continent, are the main determinants of recruitment over shorter periods and that classical stock–recruitment models cannot be applied to the European eel. It also debated the assumption that large female eels produced in the Baltic make a major contribution to overall production of the European eel (e.g. Tesch, 2003), as North Atlantic/North Sea glass eel recruitment was relatively very high around 1980, despite the major declines in Baltic stocks beginning in the 1950–1960s. In conclusion, Knights and Bonhommeau, unpubl. suggest that combined European landings data cannot be used as a simple direct proxy for stocks, certainly in different regions in NW Europe. The lack of any clear recovery in recruitment during the low NAO periods in the late 1990s led Dekker, 2004a to question the role of the NAO in affecting glass eel recruitment. However, the continual warming of the N Atlantic signalled by the rising SS-SST and NHT has probably overridden the effects of the NAO (Knights and Bonhommeau, unpubl.).

## 7.6 Conclusions and recommendations for Chapter 7: Oceans, climate and recruitment

### 7.6.1 Conclusions

- Sufficiently long time-series of glass eel recruitment, covering several periods of the natural climatic oscillation over the North Atlantic, reflect the same periodicity.
- The causal link between climate and recruitment strength, is unknown.
- It is unknown where and when during the oceanic life of the eel larvae the climate effect operates. It may be in the Sargasso Sea or closer to the European coastal area.
- The recent, prolonged strong decline in eel recruitment is out of phase with the dominating climate cycle, the North Atlantic Oscillation, although continual warming has probably overridden the effects of the NAO.

As long as the causal factors of oceanic influence are unknown, it is not safe to assume that the decline is explained by climate alone, especially while we know that the anthropogenic influences during the continental life stage of the eel are large and better understood. The fact that oceanic climate may contribute to recruitment variation is not grounds for abstaining from all possible measures to increase silver eel escapement to boost spawning-stock biomass. At some level the stock/recruitment relation will always be important-there is no recruitment without eggs. Ocean environmental factors can never justify a lack of conservation measures.

The options and expectations for management outcomes can be summarized in Table 7.3 that can be used in a risk analysis:

**Table 7.3: Options and expectations for management outcomes.**

| | Hypothesis about cause of decline | | |
|---|---|---|---|
| | **Pure stock/recruitment** | **Ocean environment** | |
| Action taken | | **Improving** | **Deteriorating** |
| Reduce anthropogenic mortality | Recovery if measures are sufficient | Recovery faster than expected | No recovery or slower than expected |
| No action | No recovery | Possible recovery | Faster continued decline |

### 7.6.2 Recommendations

To address the difficulties comparing ocean environmental cycles with biological cycles of eel it is necessary to improve our knowledge of the oceanic phases of the eel life cycle. This will allow us to better understand which oceanic factors are behind the climate effects. This in turn will allow for a more sophisticated analysis than mere correlations and the weighting of the role of climate effects on reproductive success, compared to continental factors. Some key questions are:

- The question of the interaction between leptocephali mortality and dispersion.
- The role of leptocephali in the ecosystem, including feeding and predation.

WGEEL proposes that an ICES Study Group is established to coordinate and plan research on the oceanic effects on leptocephali and metamorphosis to glass eel.

# 8 Research needs

## 8.1 Introduction

The Working Group on Eel identified a considerable need for new research on eel population dynamics and its influencing factors. Due to the current implementation of the EU eel recovery plan (EU Regulation 1100/2007), the primary focus of discussions on research requirements at WGEEL 2008 was on supporting the assessment of the stock and its recovery as sought by the implementation of this regulation. WGEEL 2008 did not, however, lose sight of the continuing lack of knowledge of the fundamental biology (i.e. carrying capacity and density-dependence) and of the European eel's ocean phase (including spawner quality and migrations). It is recognized that methods for evaluation of the outcome of management measures are not yet fully available either at the population (international target), or local (sub target) level.

## 8.2 Priority research needs

WGEEL believes that the best approach is a series of integrated and internationally coordinated projects and is set out in Figure 8.1. A programme of research is needed to address gaps in knowledge, gather data to evaluate the status of the stock, and further develop stock assessment methods to determine compliance with targets and the effectiveness of management actions at the international and local level.

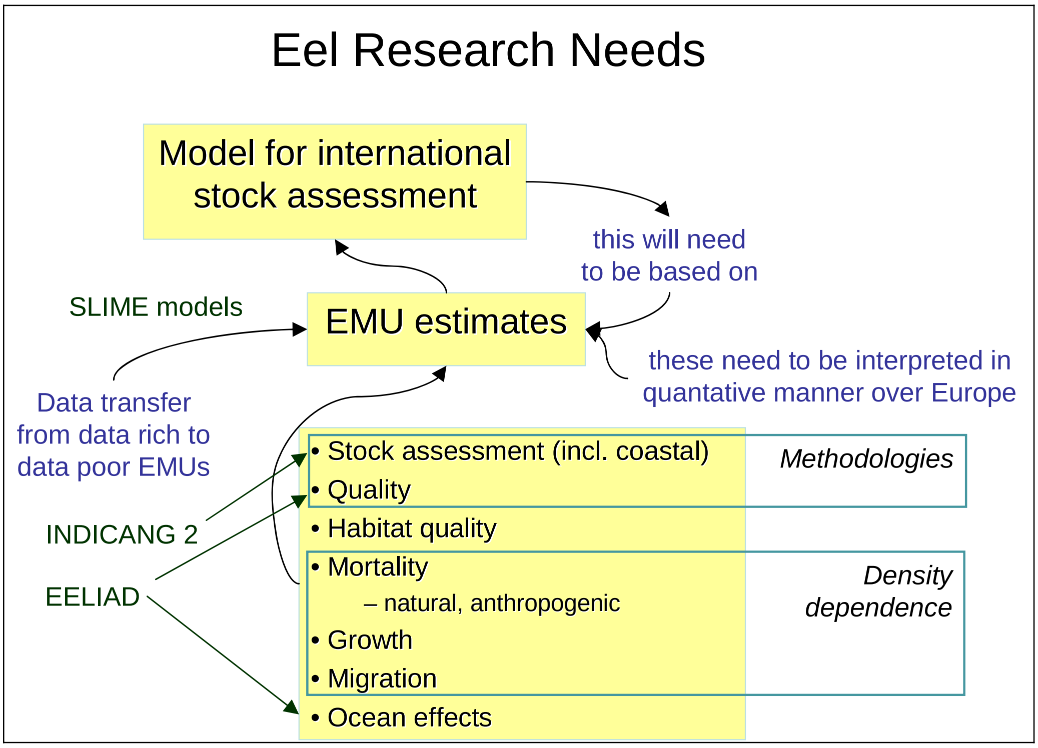


**Figure 8.1: Flow diagram showing linkages between research needs.**

The priorities for integrated research are as follows:

- International Stock Assessment and trend monitoring
- Local stock assessment and post-evaluation of management actions
- Process based research on biological parameters required for estimating escapement.

### 8.2.1 International stock assessment and trend monitoring

Improved annual trends on recruitment, stock and yield

Emigrating silver eel biomass, numbers and sex ratio

The aggregation of river basin specific data and assessments, into stock-wide assessments in support of stock to recruitment (S-R) and recruitment to spawner stock biomass (R-SSB) assessment and modelling (e.g.VPA).

The further development of models to assess compliance with the recovery target and evaluate management actions

The international assessment of recruitment and stock trends to assess the response of the stock to management actions under the Regulation, noting the WGEEL recommendation on accessibility to national eel management plans and supporting eel data.

### 8.2.2 Local stock assessment and post-evaluation of management actions

The development of local stock assessment procedures and estimates of silver eel escapement

The further development of models and methodologies to assess compliance at the local scale with the recovery target and evaluate management actions

The development and testing of methods to characterize and quantify eel stocks in deeper areas of rivers, lakes, estuaries and coastal waters

The testing of relationships between habitat characteristics, eel quality and eel production as indicators of the relative production potential for different habitats

To develop methods for quantitative assessment of the availability of local surplus for stocking, and for the contribution of stocking to escapement

Implementation of EMPs requires the development of methodologies to obtain estimates of escapement. These can be direct (*e.g.* mark-recapture or acoustic counting) or indirect methods (*e.g*. yellow eel proxies to determine silver eel production and eel habitat modelling production). Validation of indirect methodologies is required.

### 8.2.3 Process based research on biological parameters required for estimating escapement

Quantify the possible density-dependence effects in various processes including mortality, growth, movement, maturation and sex differentiation.

Quantify the impacts of pathogens, parasites, diseases, and low chemical quality on effective silver eel escapement and spawning success. This should include the relationship between eel quality and body fat content.

Quantify any impact of aquaculture, transport and stocking of eel in terms of reduced spawner production

Research is required on the relative importance of the habitat types used by eels and what demographic characteristics they exhibit in these habitats, such between fresh (rivers and lakes) and saline (brackish/salt) waters.

Recent research has suggested that processes in the oceanic phase (including spawner quality) may be important in determining recruitment levels. Improved knowledge of the oceanic phases of the eel is needed to further the initial search for correlations between eel recruitment and oceanic processes.

## 8.3 Other research needs

WGEEL 2008 focused heavily on the requirements of the EU Regulation and the need for international and national stock assessment. Additional research will be required in order to fill many gaps in the biology and management of eel.

Research on optimum collection and transport methods for glass eel to reduce mortality for stocking

Timing and frequency of stocking

Related eel health issues

Post-evaluation methods for the net benefit of stocking for conservation

Investigations examining the competitiveness, survival and reproductive capacity of stocked glass eels, compared with their naturally recruited counterparts by marking the stocked individuals and comparing their recapture at sexual maturity

Quantify the relation between fat content and eel quality, the effects of specific contaminants and parasites on fat metabolism and a possible relationship between eel fat content and environmental variables such as changing temperature, changing trophic status, and food availability

Predator prey relationships (e.g. cormorants).

## 8.4 Proposals for study groups

WGEEL proposes that an ICES Study Group is established to coordinate and plan research on the oceanic effects on leptocephali and metamorphosis to glass eel.

WGEEL notes and approves the proposal for an eel age calibration workshop.

WGEEL notes and approves the proposal to the DFC (2008) for a study group on anguillid eels in saline (brackish/salt) waters.

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