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EUROPEAN INLAND FISHERIES ADVISORY COMMISSION
INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA

Report of the thirteenth session of the

JOINT EIFAC/ICES WORKING GROUP ON EELS

Copenhagen, Denmark, 28-31 August 2001

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PREPARATION OF THIS DOCUMENT

This report summarizes the presentations, discussions and recommendations of the Thirteenth Session of the Joint EIFAC/ICES Working Group on Eels, which took place in Copenhagen, Denmark, from 28 to 31 August 2001.

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ABSTRACT

The EIFAC/ICES Working Group on Eels met at ICES headquarters, from 28-31 August 2001, to finish the work initiated at its 1999 meeting on defining biological reference points for European eel management use. The review of available information revealed that the European eel stock is in decline and that fisheries is outside safe biological limits. Anthropogenic factors (exploitation, habitat loss, increased predation, contamination and transfer of parasites and diseases) as well as natural processes (climate change) have contributed to the decline. Latest recruitment data (spring 2001) indicated a further deterioration of the status of the stock. As management at local level has failed to address the global decline of the stock, the implementation of an international stock recovery plan is of utmost urgency. The Working Group recommended that an international commission for the management of the European eel stock be formed, to organize monitoring and research on eel stocks and fisheries, and to serve as a clearing house for regular exchange of information regarding landings and resource status.

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FAO Fisheries Department
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1 INTRODUCTION

At the 87th Statutory Meeting of ICES (2000) and at the 21st meeting of the EIFAC in Budapest, Hungary, it was decided that:

The EIFAC/ICES Working Group on Eels {WGEEL} (Chair: W. Dekker, Netherlands) will meet at ICES Headquarters, from 28-31 August 2001 to finish the work initiated at its 1999 meeting on defining biological reference points for European eel management use. The Group should address the following terms of reference

- *In response to the 1998 EC request on providing escapement targets and other biological reference points on European eel for management use the Group should:*

  a) assess trends in recruitment and their causes and the effects on stock and yield of the species;
  b) investigate the impact of fisheries on spawner escapement in selected systems;
  c) define relevant units where escapement targets would be applicable;
  d) where information warrants, propose preliminary biologically-based escapement goals for selected systems;

- *propose management actions leading to the required escapement;*

- *report progress in work on improvements in the scientific basis for advice on management of European eel fisheries;* inter alia *on*

  a) development of harvest rate models for eel fisheries in data-rich systems;
  b) assessment of density-dependent processes (growth and mortality) and their impact on spawner escapement;
  c) development of reference points for management use in data-poor systems;
  d) developments of procedures to verify effects of eel fisheries management measures, in data-rich and data-poor systems;
  e) assessment of the (positive) impacts of management measures not directly related to exploitation, e.g. fish passes, habitat improvement, re-stocking, etc.

Nineteen experts attended the meeting, representing ten countries. Additionally, ICES and EIFAC officers participated. The list of participants is given in the *Appendix*.

During the meeting of the Working Group, it was felt that ongoing management and research of eel necessitated consideration of some major issues that were not fully included in the Terms of Reference. It was decided not to exclude these items from the discussions and consequently this report also contains some discussion not directly related to the TORs. This applies in particular to management of eel stocks by measures other than regulation of exploitation, i.e. management of other anthropogenic impacts and by re-stocking.

The structure of the report essentially follows the Terms of Reference for the meeting, with additional sections on issues not related to exploitation inserted where appropriate.

2 TRENDS IN RECRUITMENT, FISHERY YIELD AND IMPACT FACTORS

2.1 Trends in recruitment

2.1.1 Recruitment data series

There are relatively few data sets which provide information on the recruitment of the European eel and these do not always adequately describe the size or pigment stages (glass eel or elver) of the recruitment material. Available time-series from 19 river catchments in 12 countries were examined for trends (Table I). The data analysed were derived from both fishery-dependent sources (i.e. catch records) and fishery-independent surveys across much of the geographic range of the European eel, and cover varying time intervals. Trends were examined over the entire duration for which data were available, in particular for the period after 1980, to investigate more recent possible changes. The sources of the data are clearly differentiated in Table I.

No upward trends were observed in any of these European data sets. Over the last two decades of all time-series, downward trends were evident, reflecting the rapid decrease after the high levels of the 1970s. Over the 1980s, the trend was downwards with the exception of the Erne in north-western Ireland in which no trend was apparent. In the 1990s most series have shown fairly stable low levels. The recent years show a continued decrease and the 2001 level is the lowest on record for all series where data has been reported.

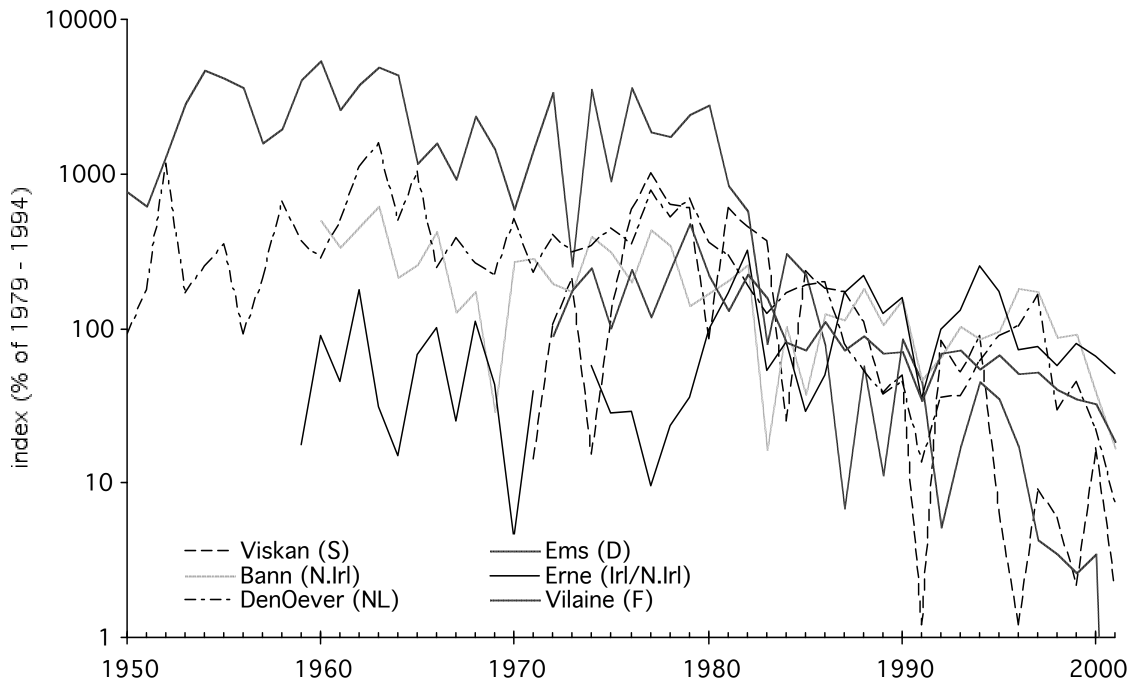


Figure 1. Time-series of glass-eel monitoring in European rivers, for which data series extend to 2001. Each series has been scaled to the 1979-1994 average.

2.1.2 Causes of the decline in recruitment

Several explanations have been put forward for the observed decline. As the timing and extent of the decline varies substantially – with a major decrease of recruitment in the Scandinavian area starting as early as in the forties and fifties whereas most continental monitoring stations see the largest decline in the eighties – it is unlikely that a single factor can explain everything. The present knowledge is not sufficient to decide between the alternative explanations and the following is a listing of hypotheses without any judgements of their relative merits.

A basic division is into anthropogenic and natural causes. For the latter the main hypothesis is a connection between the recruitment decline and a decadale scale change in the oceanic circulation (Castonguay *et al.*, 1994). The parallel decline of the recruitment of the American eel in some of it's distribution area, and the correlation between recruitment and the North Atlantic Oscillation Anomaly supports this model (ICES, 2001). Other natural causes that have been discussed are different diseases – viral infections or the swimbladder parasite *Anguillicola crassus*. This parasite spread rapidly in the European eel population in the early eighties. Infection causes swimbladder dysfunction and may impair the migration of mature eels. Predation by the greatly increased European populations of cormorants or other predators has also been discussed.

Fishing and habitat loss are the main anthropogenic factors. The impact of the eel fishery is discussed in Chapter 3.1. A large part of the European inland water habitat has been made inaccessible to eels by hydroelectric dams or other obstructions to upstream migration (Chapter 3.3). Even where recruits can pass in eel ladders, or are trapped and transported upstream, the loss of escapement can be substantial due to a high mortality when the silver eels pass through turbines during the downstream migration. In addition to the loss of habitat by obstructions, large areas of wetland have been lost through draining and land reclamation. Even very small streams and ponds are suitable yellow eel habitats. The total change of available inland areas for eel is unknown, the process has occurred gradually, mainly during the second half of the twentieth century.

The spread of environmental contaminants may contribute to the recruitment failure. The burden of persistent contaminants in inland and coastal waters has increased both in amount and number during the early period of decline, but during the more recent decline in the eighties the trend has been the reversed. Eels accumulate organochlorines and other fat soluble substances readily, and this may impair the migration and affect the survival of the larvae. A concern expressed more recently is the spread of endocrine disruptors.

2.2 Trends in stock and yield

2.2.1 Landings statistics

The Food and Agriculture Organization of the United Nations (FAO, Rome, Italy) maintains a database of fishing yields. Additionally, the International Council for the Exploration of the Sea ICES (Copenhagen, Denmark) maintains a database of landings of marine, Atlantic fishing yields. As the data in the ICES database exclude the major yield from the stock at forehand, i.e. the inland catches, preference was given to the FAO data.

Official landing statistics for many countries comprise only about half of the true catches in the 1980s and 1990s (ICES, 1988; Moriarty and Dekker, 1997), because of illegal and unreported catches, as well as lack of coverage of many areas in several countries. However, to some extend trends in the reported data will reflect true changes in fishing yields.

FAO eel landing statistics are presented in Table II and Figure 2. The data show a clear decrease of yield during the last 20 years in Denmark, Netherlands, Italy, France and Portugal. In Sweden, Germany, Spain and the United Kingdom a less pronounced decrease is observed. In Ireland a marked increase in catches has taken place possibly because the eel fishery was developed over this period. In Norway the catches seem to be stable.

The FAO catch return data do not necessarily reflect the status of the eel stock. Effort can be variable and underreporting the catches is a serious problem in most countries.

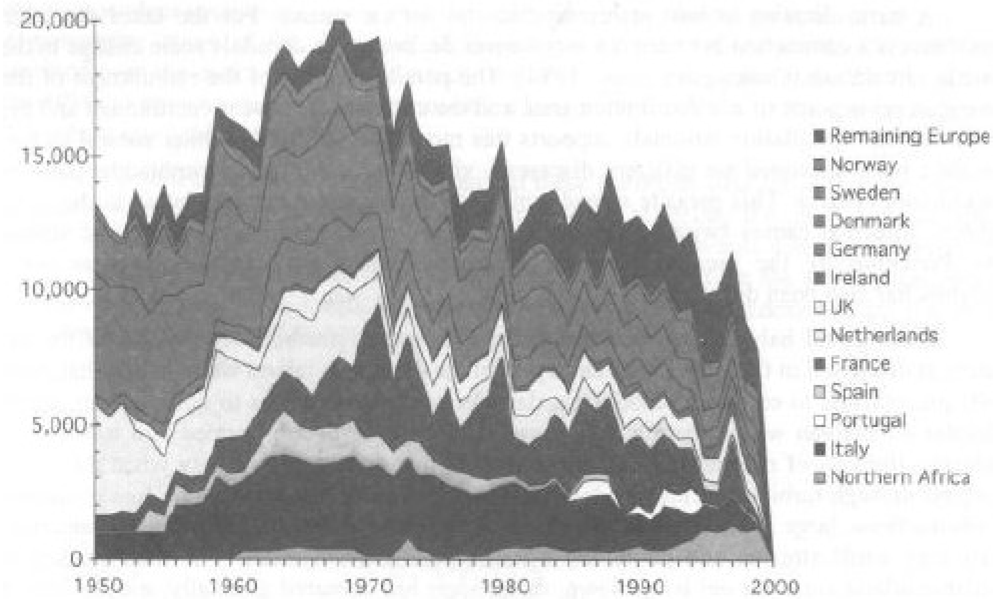


Figure 2. Landing statistics of the European eel in the past 50 years, as reported by FAO data base, with minor corrections.

2.2.2 Impact of recruitment decline on stock and yield

Impact on glass eel fisheries

In England and Wales, only hand-held dip nets are permitted for the capture of glass eels/elvers and fishing is concentrated in areas of high recruitment/easy capture, principally in estuaries of the River Severn and other rivers draining into the Bristol Channel. The number of licenses purchased per year was fairly constant at ~1 000 until 1994, but then rose to a peak at ~2 500 in 1997-98 as catch values increased due to demand for seed stock from new eel farms in China (Figure 3). Licence numbers subsequently declined to <1 500 in 2000 (data not included in Figure 3) as a result of farm-overproduction and imposition of import quotas by the Chinese. Provisional information suggests licence sales in 2001 were particularly low due to restrictions on access to fishing sites because of foot-and-mouth disease regulations.

There are few reliable catch records for eel in England and Wales. Catch returns are required from commercial licensees in some areas, but return rates are sometimes low. Commercial catches are commonly believed to be under-reported, as fishermen are reluctant to disclose such information due to perceived income tax implications. Catch data (available returns combined with estimates) have been collated by the Ministry of Agriculture, Fisheries and Food (MAFF) and reported annually (Figure 4). It should be noted that these data are considered to be very incomplete and of variable accuracy, both as a consequence of the factors outlined above and because assessment methods have varied between regions and from year to year.

As the great majority of eels caught in England and Wales are exported, estimates of the catch have also been possible from customs and excise export records (Knights *et al.*, 2001). Separating exports of recruits (glass eel and elver) from yellow/silver eels (not readily apparent from customs records) has necessitated estimating the quantities and total values of glass eels on the basis of their relatively much higher value per unit weight. Adjustments have also had to be made to allow for imports/trans-shipments of glass eels. The customs and excise records have sometimes appeared to be incomplete or erroneous (especially in recent years following liberalization of inter-EU trade). Further complications have arisen from the fact that some exporters have not declared all shipments or the sources of eels. However, despite these caveats, the export data generally provide a reasonable match with the trends in catch data (Figure 4), as well as being in broad agreement with data on recruitment, catches and markets elsewhere in Europe.

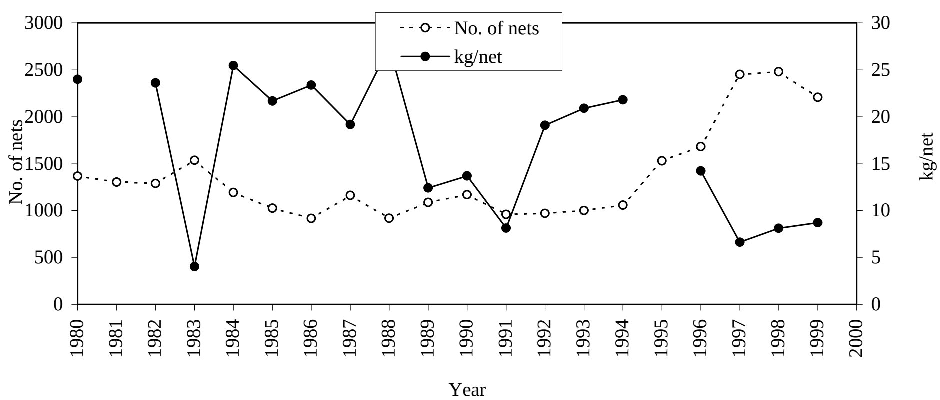


Figure 3. Glass eel fishing effort (no. of licensed nets) and CPUE (from export data) as kg/net, 1980-1999

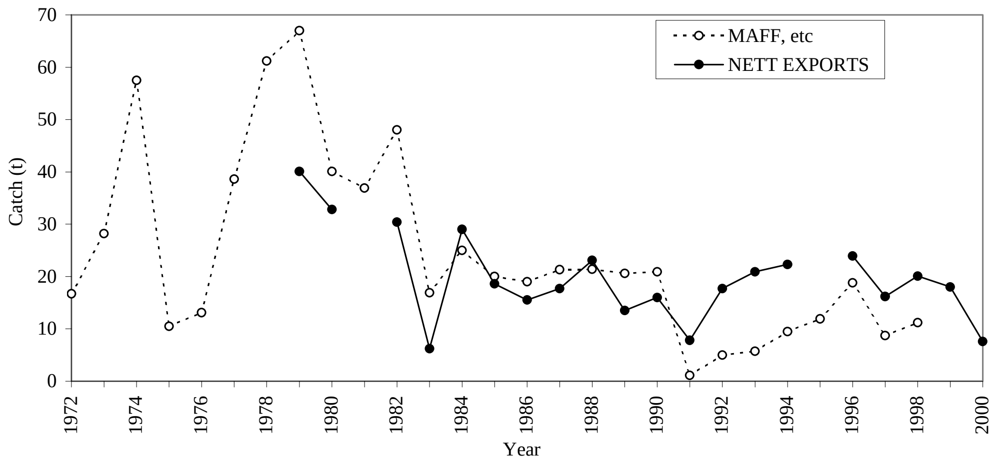


Figure 4. Glass eel catches (t) from MAFF/Environment Agency and export data, 1972-2000.

Impact on yellow eel fisheries

The quality of the eel catch data and the large and varying lag between arrival as glass-eels and recruitment to the fishery makes it difficult to demonstrate a causal link between recruitment and yield in the fisheries statistics. A case where long and relatively good quality data sets exist is the Swedish silver eel fishery in the Baltic (Svärdson, 1976). As an index for the recruitment to the Baltic the monitoring of recruits caught at an eel-ladder in a major river on the Swedish west coast (Göta Älv) has been used. The catch in the Baltic is dominated by females and a typical age at maturing is 15-25 years. Figure 5 shows the two data series. The decrease in recruitment clearly precedes the decrease in catch.

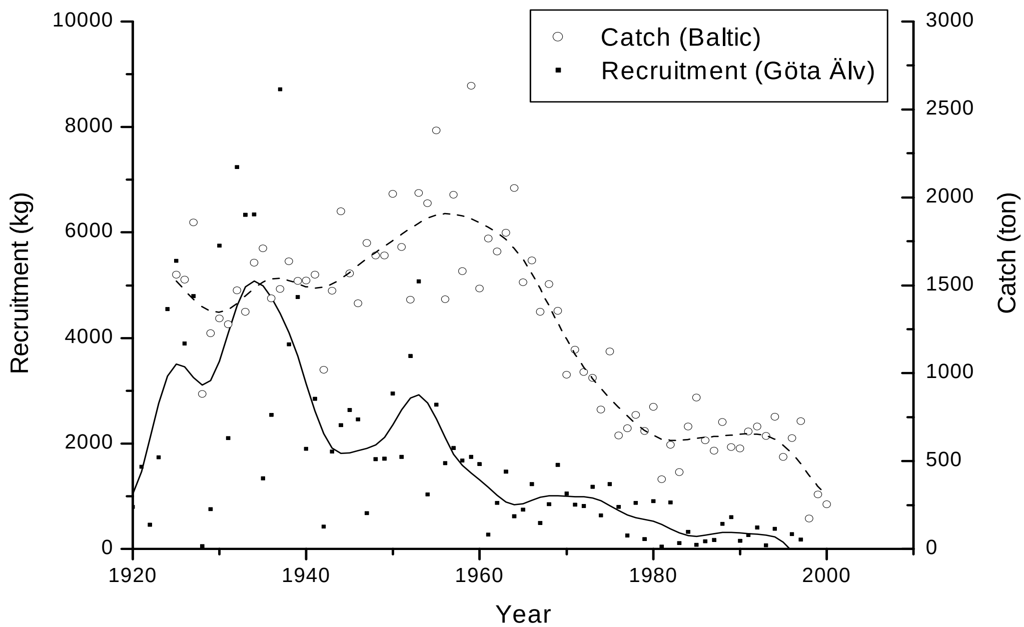


Figure 5. Time series of eel catches in the Swedish Baltic, including the Sound, and the recruitment immigration in a river on the Swedish west coast. The scattered points are annual values and the lines show 5 year FFT averages. No correction has been made for changes in fishing effort.

Stock in England and Wales

The decline in recruitment since 1980 has occurred almost all over the distribution area in synchrony (Dekker, 2000a). In the British Isles, however, the decline was much less pronounced. Additionally, the situation in England and Wales deviates from the remaining areas, in the sense that exploitation of the yellow eel stock is only marginal.

Recruitment in England and Wales has declined from peak values in the late 1970s, mirroring the changes seen elsewhere in Europe. Quantitative assessments of changes in eel stocks over the past 20 years have generally been hampered by a lack of robust time-series data. Surveys carried out in 1999 (Knights *et al*., 2001) on three catchments (Rivers Frome, Piddle and Dee) subject to low levels of exploitation, and for which reliable data from the 1970s and 1980s exist indicated the following:

- In the Frome and Piddle there has been a decline in biomass and in density, the decline being greater in terms of biomass. There appears to have been a decline in the number of glass eels entering the rivers as the number of eel < 150 mm is very low. The sex ratio in both rivers has changed from being previously male dominated to one where females now dominate the mature population.
- In the Dee, there was no indication of a significant change in either density or biomass, nor in the size structure of the population.

Examination of less robust data sets for a number of other rivers, indicated no statistically significant decline in stocks of yellow eels or changes in population structure over the last 20-30 years. However, the absence of widespread detectable changes in yellow eel standing crop/population structure should not lead to an assumption that recruitment is necessarily adequate, as in the majority of instances the programmes were not set up or designed to monitor change. In addition, given the relative longevity of eel, declining recruitment will have a delayed effect on the densities of eel in freshwater systems and the resulting spawner escapement. Thus the recent (and ongoing) decline in recruitment could lead to changes in the future.

2.3 Trends in restocking

Data were obtained from a number of countries, separately for glass eels/elvers and for bootlace eels. The size of 'bootlace eel' varies between countries. Most data available were on a weight basis. Weights were converted to numbers, using estimates of average individual weights of the eels stocked. These were 3.5 g for Denmark, 33 g for the Netherlands, 20 g for (eastern) Germany, and 50 g for Sweden. An overall number of 3 000 glass eels per kg was applied.

Recent time series available were available from (eastern) Germany, Netherlands, Sweden, Denmark and Northern Ireland. For Poland, an older time series was available. These are presented in Tables III and IV. In addition, some anecdotal information on re-stockings is available.

A downward trend in the level of re-stocking glass eels is observed since the early 1980s, down to 15 percent of former level (Figure 6). The level of re-stocking with bootlace eels has increased since then by 250 percent (Figure 7). The combined level of re-stocking (glass eels and bootlace eels) has decreased to 25 percent of the early 1980-level. Data from the Netherlands and Northern Ireland are available on the amount of intra-catchment re-stocking as compared to inter-catchment stocking (Table V). The percentage of intra-catchment stocking in the Netherlands increased in the 1990s to an average of 40.7 percent since 1990. In Northern Ireland the river Erne is re-stocked by intra-catchment transfers only. The percentage of intra-catchment re-stocking in Lough Neagh decreased from the early 1980s, to an average of 84.3 percent since 1990.

Re-stockings in the Republic of Ireland are dominated by the Shannon. Intra-catchment re-stocking of glass eels and bootlace eels in the river Shannon occur since 1958. The current average rate is 1.2 million recruits per year. The majority of these re-stocked eels are just pigmented.

The only data available for France are from the river Rhone. Barral (2001) estimates the total weight of re-stockings in the Rhone since 1978 at 22 000 kg (total over all years), 94 percent from intra-catchment stocking of bootlace eels (mainly 50-100 g) and the remainder from glass eel stockings from the Atlantic. Probably these Rhone data are underestimated due to incomplete recordings.

Ciccotti (1997) describes the re-stockings in Italy, dating from centuries ago in the valli di Commacchio. In 1978-1982 re-stockings amounted to 0.4 million bootlace eel on average, imported from France. From 1990 onwards re-stocking practices have been abandoned. In the whole of Italy on average 35.2 million glass eels were stocked in 1988-1990. The origin of these glass eels is unknown. Additional stocking of 17.5 t of bootlace eels occurred but there is no information available on the sizes and numbers of these eels.

There are no current stockings in England and Wales. Historically these occurred on small scale, probably more than 15 years ago and intra-catchment.

Intra-catchment re-stocking of un-specified sizes of eels in Norway have been described for the Imsa river only during 1983-1996. These amounted to 0.2-13 kg and were lower than 1.0 kg since 1994.

Re-stocking of eels does not occur in Portugal and Spain.

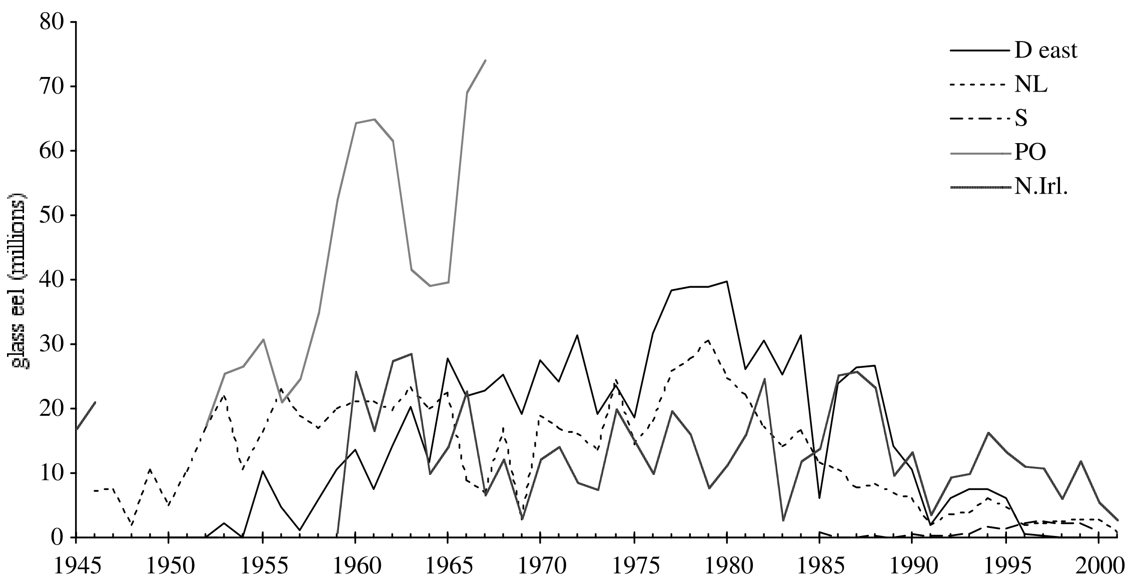


Figure 6. Re-stocking of glass eels in the Eastern part of Germany (D east), the Netherlands (NL), Sweden (S), Poland (PO, until 1967) and Northern Ireland (IR North).

There is no information on re-stocking available for Western Germany, Belgium, Finland, the remainder of the Baltic states, North-African states and states along the Eastern Mediterranean Sea.

Of all these countries where time series are lacking, probably only Italy, Ireland and the Western part of Germany are relevant for the totals. The Italian data in 1988-1990 show a level of re-stocking glass eels/elvers comparable with the cumulated data for Eastern Germany, the Netherlands, Northern Ireland, Denmark and Sweden. Applying the same trend in reduction of re-stocking to the Italian data, and considering that the current re-stockings of glass eels in the remaining countries probably do not exceed 5 million/year, this will give an estimate of the current re-stockings of ca. 30 million glass eels (10 tonnes) per year in Europe.

This is considerable less than the 33 tonnes mentioned by Moriarty and Dekker (1997). An unknown percentage of this amount concerns intra-catchment re-stocking but available data suggest that this may be substantial.

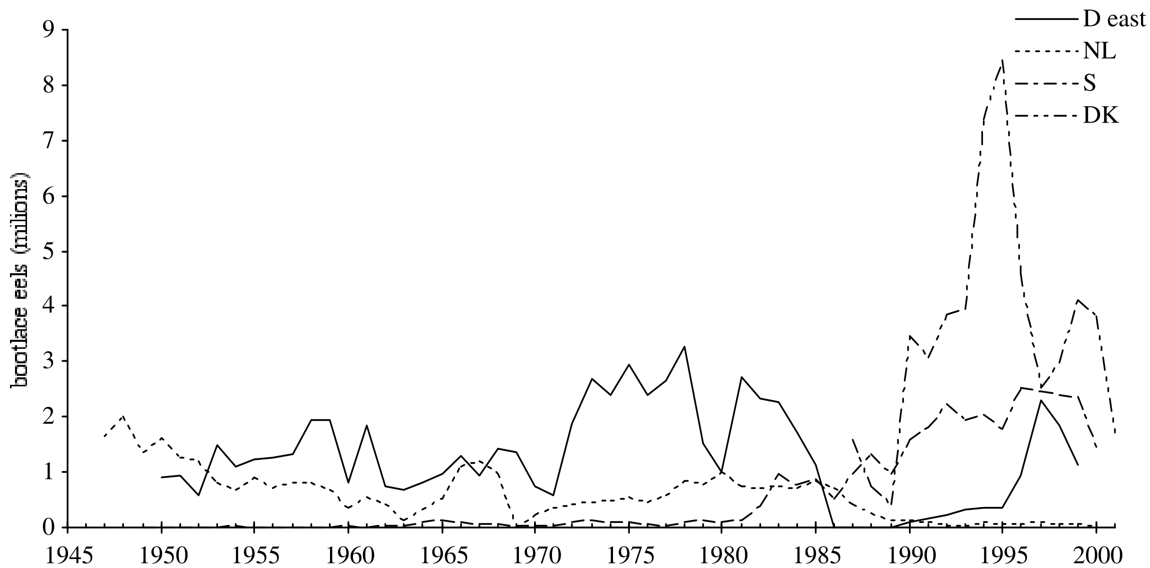


Figure 7. Numbers of bootlace eels re-stocked in the Eastern part of Germany (D east), the Netherlands (NL), Sweden (S) and Denmark (DK).

2.4 Trends in aquaculture

Aquaculture of the European eel ranges from highly industrialized, indoor facilities in northern Europe, through extensive culture in artificial ponds in southern Europe, to re-stocking of foreign glass eel in semi-natural outdoor waters for fisheries in northern Europe. All aquaculture fully depends on seed stock derived from the wild population, since artificial reproduction fails in the young larval stage. Additionally, aquaculture plants are used for quarantine of foreign glass eel to be re-stocked in outdoor waters (e.g. Sweden) and transports of half-products in-between aquaculture and fisheries occurs in and between countries (France, Italy). Obviously, the distinction between aquaculture and fisheries is hard to define.

For aquaculture production, no consistent long running time series exist. Data are available from FAO, from the Federation of European Aquaculture Producers, from previous meeting of the working group and from Kamstra (1999). An overview of the estimates is compiled in Table VI. In addition to the aquaculture in Europe, Eastern Asia (originally Japan, but recently predominantly China) has a large aquaculture industry, also culturing European eel.

Aquaculture of the European eel has started much later than the culture of the Japanese eel. In 1970, the European production was estimated at 3 400 tonnes, while the culture of the Japanese eel amounted 17 000 tonnes. In the early 1970s, European eels were cultured in Japan for a small number of years, with little result (Egusa, 1979). Since the mid-1980s Japanese culture of European eel has risen from 3 000 tonnes to 10 000 tonnes nowadays. The European culture of the European eel is now estimated at 10 000 tonnes (Kamstra, 1999). This is to be compared to 40 000 tonnes of Japanese eel being cultured.

The aquaculture production in Europe is concentrated in Denmark, the Netherlands and Italy. The aquaculture in Denmark and the Netherlands is technically speaking highly developed and produces an increasing part of the total, while Italy has intensive as well as extensive culture systems, the latter with a declining production.

The landings from fisheries reported by FAO have declined from ca. 20 000 tonnes in 1970 to less than 10 000 tonnes nowadays (Section 2.2.1). This has coincided with a rise in European aquaculture production from almost nil in 1970 to 10 000 tonnes nowadays. This suggests that the total production in Europe has remained level. However, fisheries production is known to be almost twice the reported statistics, due to underreporting. Additionally, the rapid expansion of the East Asian production and consumption has resulted in the eel trade now being a global market, in which the apparently level European production is only one of the smaller constituents.

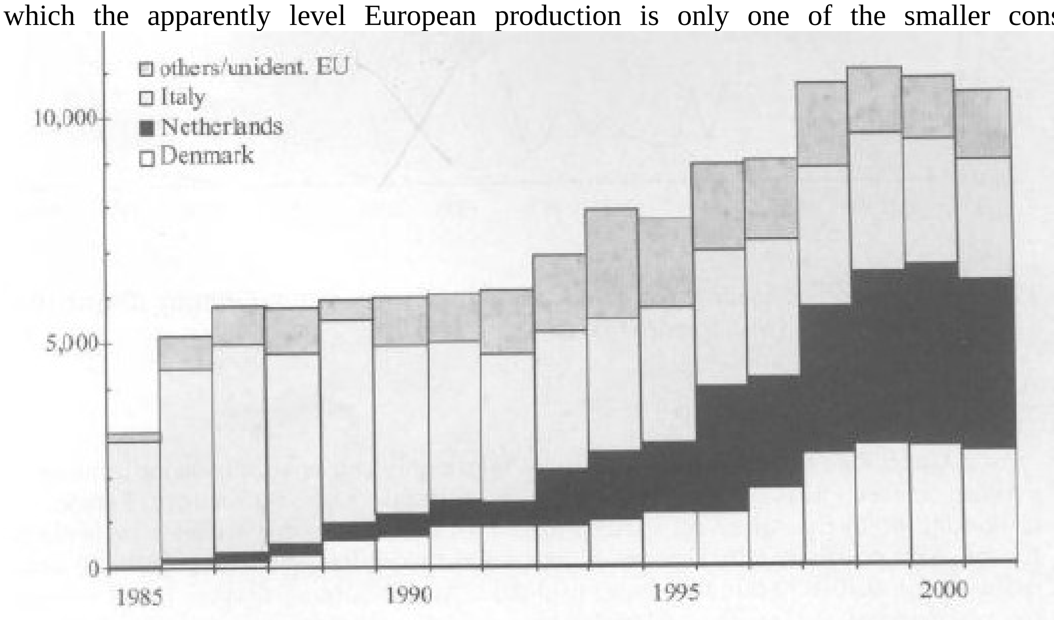


Figure 8. Trends in aquaculture production of the European eel.

3 ANTHROPOGENIC IMPACTS ON THE EEL STOCK

3.1 Impact of fisheries on spawner escapement

The maturing stages of eel have never been observed in the wild, but are undoubtedly purely oceanic in nature. Escapement of silver eel from the continent provides the best indicator of oceanic spawning stock biomass, but silver eel escaping the continental fisheries are probably more correctly defined as pre-spawners. There are no means available to assess potential losses between silver eel emigrating from freshwater and the oceanic spawning phase in the life cycle. Consequently, discussion will focus on the impact of fisheries on silver eel escapement.

The information available with regard to the impact of fisheries on silver eel escapement is very limited relative to the number of fisheries operating and there are few estimates of fishing mortality. Where available, mortality data have been provided, but these are inconsistent; both, instantaneous values and estimated losses over the freshwater phase have been included (see also Knights *et al*., 2001). The data tend to be restricted to larger intensive fisheries that are not necessarily typical of the overall situation across the range of the species (Dekker, 2000a). These larger fisheries are geographically discrete, with the major glass eel fisheries mainly in the Biscay area and SW England, the freshwater yellow/silver eel fisheries concentrated in mainland Europe and Ireland, and fisheries in the Baltic focussing on silver eel more than elsewhere. The larger fisheries contribute only a small proportion of the total European catch (~5 percent, Dekker, 2000a). It is thus important to recognize that the following examples do not provide full insight into escapement processes of the species over its whole geographic range.

3.1.1 Impacts of emigrant silver eel fisheries on escapement

The most significant silver eel fisheries are based in the Baltic (using pound nets and similar passive devices) and in Lough Neagh, N. Ireland (using silver eel traps on the River Bann). A conservative estimate of overall escapement of silver eel from European waters is 553 tonnes (Moriarty and Dekker, 1997), but a Procrustean estimate based on all available evidence amounts to 1753 tonnes (Dekker, 2000c). Although there are no firm data, actual escapement is believed to be high in some river-based silver eel fisheries, due to inherent gear inefficiencies and current management actions to promote escapement (see below). In the Baltic, where silver eel dominates the catches, Wickström and Hamrin (1997) estimated using mark-recapture/mean recapture rates by commercial fishermen of between 35 and 49 percent, but could be as high as 69 to 76 percent. In the western Baltic, Pedersen and Dieperink (2000) reported recaptured rates of Carlin tagged silver eel in three pound net fisheries. Recapture rates varied between 19 and 38 percent and was dependent on the location and size of the fishery. The results indicate a high level of fishing mortality in the Baltic Sea which is further supported by the relatively short time interval between release and recapture of less than 16 days. These fisheries thus exploit the larger, more fecund, females. In addition, there are concerns about the ability of stocked eel to migrate successfully out of the Baltic.

The value of the above escapement estimates with regard to ensuring an adequate spawning stock biomass is restricted, due to low geographical coverage. It is impractical to set separate escapement targets for either sex, but it is emphasized that females being larger and older at migration are more vulnerable to capture (and turbine mortality in power stations) than males. Therefore, increased emphasis should be given to protecting females.

It seems reasonable to assume that density dependent processes do not operate in the oceanic migration towards the supposed spawning places. As such the percentage decline in silver eel escapement probably produces similar decreases in spawning stock biomass on the spawning grounds.

3.1.2 Impacts of yellow/silver eel fisheries on spawner escapement

The major yellow/silver eel fisheries are the Italian lagoons and the fyke net/long-line fisheries of the Netherlands, Germany, Denmark and N.Ireland. There are few reliable data sets with regard to effects on spawner escapement. The Italian lagoon fisheries are mainly closed and stocked systems and escapement can generally be regarded as zero. Estimates for the mortality rate in the IJsselmeer fishery are extremely high (F = 1.0; Dekker, 2000b) and spawner escapement is estimated to be low for males and practically nil for females. Exploitation of yellow eel in Lough Neagh is also high and, although not quantified, escapement of silver eel is assumed to be in the region of 20-25 percent of the yield of the fishery. These two quantified larger scale fisheries (IJsselmeer and Lough Neagh) constitute a notable part of the total yellow/silver eel fisheries. They cannot be considered to be representative of the multitude of smaller fisheries that make up the rest (Dekker, 2000a), due to highly variable levels of exploitation. Consequently, accurate assessment of the continent-wide escapement is unachievable (Dekker, 2000b). Along the west coast of Sweden pound net and fyke net fisheries can be relatively efficient, catching more than 96 percent of the stock between 370 and 650 mm (Svedäng, 1999).

The above examples illustrate that yellow eel fisheries can impact upon silver eel escapement. The effect of other yellow eel fisheries on spawner escapement is unknown. However, assessment of lake IJsselmeer fisheries (Dekker, 2000c) suggests that even moderate exploitation of yellow eel results in substantial reduction in silver eel production. Dekker (2000c) showed that if a yellow eel fishery was operating at F_{max} (in the case of the IJsselmeer the minimum legal size is 280 mm) then the spawning escapement would be reduced to 10 percent of the unexploited biomass. As such, controlling yellow eel fisheries below their local optimum might be crucial for sustained exploitation of the stock.

3.1.3 Impacts of glass eel fisheries on spawner escapement

The reduction in egg deposition as a result of glass eel exploitation will be equivalent to the exploitation rate only if there is no density dependent change in sex ratio, growth, survival or emigration rate of the subsequent life stages. This, however, is not assumed to be the case.

The major glass eel fisheries are based on estuaries facing the Atlantic coast of France, Spain, Portugal and south-west England (Bristol Channel). The major market in the past was for direct human consumption in Spain and Portugal, plus stocking in central, northern and eastern Europe. However, high demands as a seed source for aquaculture in Europe (Italy, Netherlands and Denmark) and, in particular, the Far East, have recently resulted in very high prices. Effectively, none of the glass eel catches used in aquaculture yield spawners. Limited re-stocking of cultured eel has been initiated in some parts of Europe, but this appears to be mostly for the benefit of fisheries and is assumed to produce relatively few spawners.

There is little information on the impact of glass eel fisheries on recruitment into freshwater or the subsequent escapement of silver eel, for selected systems. However, natural mortality (exacerbated by density-dependent factors) is expected to be very high where abundance is very high in relation to the carrying capacity of the receiving river. Glass eel runs that exceed a river's carrying capacity may be a source for transfer to other rivers (but may also be important in contributing to the overall ecosystem). In the River Severn, Knights *et al.* (2001) compared the density of yellow eel in 1998/1999 with that found in 1983. The authors concluded that there was no substantive evidence for a major change in eel density or biomass over the time period even though there had been a major decline in recruitment of glass eel to the system since the early 1980s. The authors did, however, report a significant reduction (ca. 50 percent) in the proportion of eel <150 mm in sites from the lower Severn between the two time periods. Conclusion of impact or lack of impact must be made with caution as comparison between the surveys in 1998 and 1999 indicated large temporal variability (ca. 30 percent) in density and biomass.

In France, very high levels of fishing mortality have been recorded in certain glass eel fisheries. For example, it ranges from 20-25 percent in open estuaries such as the Adour, to 98 percent in closed estuaries such as the Vilaine (Briand *et al.*, 2000a). On the River Loire, a model showed that a decrease in glass eel recruitment is followed by a reduction of yellow eel population biomass 8 to 15 years later (Feunteun *et al.*, 2000a). This is consistent with an observed reduction in subsequent silver eel catches (Boisneau and Mennesson-Boisneau, 2001). In another example, on an obstructed catchment (River Vilaine, Brittany) which has very high fishing effort on glass eel, a reduction from 99.6 percent to 96 percent in fishing mortality and the use of a fish ladder may have resulted in an increase (2.8-fold) in the density of yellow eel in the watershed (Briand *et al*., in press, a). The migration and settlement pattern in the lower reaches of the river would suggest that this section of the catchment was at carrying capacity.

3.1.4 Impact estimates

Information is required on the relative impacts of fisheries compared to natural causes of mortality at different stages of the life cycle in order to help clarify whether stocks are being over-exploited or whether fishery control measures are required. Estimates of natural and fishing mortality on a case by case basis are presented in Table VII.

On the basis of this limited available information it is evident that fishing mortality can equal or exceed natural mortality. A brief qualitative assessment of the impact of fisheries in the various countries is presented in Table VIII. This table summarizes the educated opinions. Impact was classified into three categories; low where fishing mortality was equal to or less than natural mortality ($F \leq M$), optimal where the maximum yield per recruit was being obtained from the fishery (F_{max}) and over-exploited where growth-overfishing will be evident ($F \geq 0.1$). In the latter case, the spawning escapement is considered to be minimal. In some cases, however, depending on the legal size limit of the fishery, operating at F_{max} can reduce the spawning escapement to 10 percent of the unexploited biomass (Dekker, 2000b).

Overall, yellow eel exploitation is low in areas where fisheries predominantly target glass eel (England and Wales, France and Iberian Peninsula). Elsewhere, fisheries are most often optimized for yield.

3.1.5 Conclusion on impact of fisheries

It is impossible to assess the effect of fisheries on the overall escapement of the European eel stock with any real confidence as there are insufficient data and existing estimates for specific fisheries are mostly rather crude. Hence, stock-wide management targets can not be derived. However, the available information indicates that fisheries on all life-stages *can* and often *does* impact upon spawner escapement within particular locations and further suggests that some fisheries are capable of completely precluding escapement of potential spawners from a catchment or fishery. It follows that further controls on local fisheries on all components of the stock are appropriate and should contribute to the overall enhancement of production and escapement of spawners.

3.2 Effects of transfers and re-stocking of eel

3.2.1 Magnitude of re-stocking

Re-stocking of eel has a long tradition, in some countries going back to the nineteenth century or earlier. It has been practised in nearly all EU-states, several middle and eastern European states, in northern African states and Norway. Due to the increasing prices, higher demands for aquaculture and lower catches, the re-stocking of inland waters in Europe with glass eels has dropped to ca. 15 percent of the early 1980s level. This is equivalent to 5 percent of the most recent estimate of the total glass eel catch (583 tonnes per annum, Moriarty and Dekker, 1997). Although the re-stocking of bootlace eels increased since the early 1980s, the combined numbers re-stocked (glass eels and bootlace eels) decreased to 25 percent of the early 1980s.

The amount of glass eel used for re-stocking (both from inter-catchment and intra-catchment transports) may exceed the natural recruitment in some of the glass eel importing countries (Dekker, 2000b). Intra-catchment re-stockings are transfers within a catchment. Inter-catchment stockings are transfers between catchments.

3.2.2 Re-stocking and local populations

Both transports within and between river systems have occurred. Transports within river systems consist of estuarine glass eel fisheries for stocking up-river areas (e.g. glass eel in the river Bann being re-stocked in Lough Neagh). Transports between river systems involves re-distribution of glass eel over rivers within countries (e.g. Swedish west coast catches being re-stocked at the east coast) as well as long-distance international transports from the Bay of Biscay and the Bristol Channel to northern and eastern Europe (e.g. development of eastern European fisheries outside the natural distribution area).

Knights and White (1998) have described effects of eel transfers on local eel populations. Experiments show reduced growth at higher densities, but it is unknown whether these densities are reached in re-stocking practices. Re-stocking, therefore, might induce a decrease in growth rate in recipient populations if carrying capacity is exceeded. There are indications for differences in growth performance of glass eel originating from geographically different regions (Klein Breteler, 1994).

Fisheries, handling and transport of glass eel for re-stocking generate a mortality of unknown magnitude. Little information is available about mortalities of glass eel in the estuaries in the traditional donor areas. Mortality of ascending eel has been shown to be density-dependent within a year-class, but densities comparable in magnitude to the natural recruitment in the Bay of Biscay have not been assessed. Glass eel densities in donor areas are probably so high that most glass eel will die naturally when not fished; re-stocking will undoubtedly improve overall survival of the recruitment material in any year (EIFAC/ICES, 2001).

In several cases an increase in relative numbers of male eel has occurred following re-stocking. Higher densities of eel also seem to be related to a dominance of males. Transfer of glass eel from areas of high eel density to areas of low eel density may promote the overall production of females.

Transfers of eel, for trade and for re-stocking purposes, present risks of spreading diseases and parasites. *Anguillicola crassus*, a swimbladder parasite, has invaded wild eel populations throughout Europe after unintended introduction from the Far East. Negative effects of this parasite on local eel populations have been reported. Risks of transfers of diseases or parasites apply particularly to transfers of eel between catchments but, to a lesser extent, also apply to transfers within catchments.

3.2.3 Re-stocking and spawning stock

Homing of silver eel derived from transfers

Re-stocking of glass eel and/or bootlace eel increases local eel stocks and might eventually result in higher escapement of silver eel. However, there are indications that silver eel derived from re-stocked French glass eel show a reduced ability to successfully navigate their way out of the Baltic Sea on their spawning migration (Westin, 1998). The contribution of re-stocked eel has therefore been questioned by EIFAC/ICES (2001).

Genetic Considerations

Recently available genetic evidence does not support the long established view that a single spawning stock breeds panmictically in the ocean (Wirth and Bernatchez, 2001).

Results from genetic studies suggest that three putative, genetically distinct sub-groups may exist:

- *Northern European* - corresponding to the Icelandic stocks
- *Western European* - including Mediterranean, western European and Baltic stocks
- *Southern European* - corresponding to eel stocks of Morocco.

If natural gene flow between the putative sub-groups is high, the risks associated with transfer and re-stocking is low. Data on gene flow are not available.

Contributions to the escapement

Contributions of re-stocking to the escapement of eels depend on mortalities, both natural and by fisheries, mortalities by hydropower stations included. There are no case studies available in which mortalities of both re-stocked and not-re-stocked eels from the same original population are compared. Generally the re-stockings occur in more upstream and more isolated waters as compared to the downstream catch places, giving more and better opportunities for the fisheries and hence, possibly, higher mortalities. Higher growth rates of the re-stocked eels may occur due to lower densities and, therefore, lower natural mortalities may counterbalance possible higher fisheries mortalities. The quantitative net effect is unknown and will largely depend on local factors.

3.2.4 Re-stocking and fisheries

Re-stocking can be a cost-effective means of restoring or maintaining yields in fisheries (Knights and White, 1998). To this end, it is essential in catchments with barriers where fish passes are ineffective and in isolated waters suitable for eel. Stocking in the Baltic and in Central-European countries occurs mainly because of shortages in recruitment and reflects the unequal distribution of recruitment material across the range of the European eel.

Lough Erne fishery is completely dependent on re-stocking, and glass eel re-stocking contributes to the Lough Neagh fishery. Eel fisheries in the inland waters of the Baltic countries (specifically Poland and the eastern part of Germany) depend almost completely on re-stockings. Dutch fisheries (excluding lake IJsselmeer) also rely upon re-stockings. Yield per re-stocked recruit (glass eel) ranges from 20 to 90 g in the Baltic, but figures for Lough Neagh and Lough Erne fisheries are substantially lower.

3.2.5 Re-stocking and other components of ecosystems

Introductions and re-stocking of eel can affect the abundance of the crayfish *Astacus astacus* and possibly also signal crayfish *Pacifastacus leniusculus* when the stock density is high and the crayfish are under ecological pressure. Impacts on other common crayfish species, such as *Austropotamobius pallipes* have not been assessed. There are no known effects on native local fish populations, except where densities of eel are high or under extreme environmental conditions.

3.2.6 Re-stocking in obstructed water systems

Regulation of natural river systems has obstructed migration routes of eel in many catchments. In these cases, re-stocking of glass eel derived from down-stream sources restores former local natural conditions and may contribute to the escapements. Of the total of 87 335 km^2 of continental waters, 3.6 percent have been classified as ‘artificially obstructed’ (Moriarty and Dekker, 1997). Hydropower stations reduce the chance of successful emigration of silver eel, in particular for the larger female eel. Eel ladders, downstream migration facilities for silver eel and intra-catchment re-stocking should be considered for restoration of eel stocks in obstructed waterways.

3.2.7 Conclusions on re-stocking

- The magnitude of the current re-stockings of glass eels is about 5 percent of the total recruitment of glass eel on the European coast. Part of it concerns intra-catchment re-stockings. Most bootlace eel re-stockings are intra-catchment re-stockings.
- The current re-stockings generally contribute to the fisheries.
- It is unknown to which extent re-stockings contribute to the escapement of silver eel.
- Escapees from long-range re-stockings may not be able to find their spawning places, but there are no indications of genetical impacts, provided that no Moroccan or Icelandic eels are used.

3.3 Impact of habitat loss on the stock

Fisheries for eel are wide spread and the assessment of the impact of exploitation has a long tradition. Clearly, management of eel fisheries is an essential part of a management plan. However, sustainable management and a stock recovery plan should also take into account anthropogenic impacts upon the stock, other than exploitation. The decline of the eel in Europe is often related to the decline of its continental habitat, its accessibility and its quality. The relative magnitude of these factors, in relation to the impact of exploitation, has not been quantified, but it seems likely to be significant in many European countries.

Among 69 European rivers studied to establish a new EU Water and Wetland index, only five (in Finland, Scotland, Wales and UK) were considered to be almost pristine and 50 were of poor quality due to impacts of canalization, pollution and altered flow regime (www.panda.org/europe/freshwater/wwi). Good ecological status as required by the EU Water Framework Directive currently is only met in the upper reaches of the 14 largest rivers in Europe, amongst which are: the Rhône, the Seine and the Loire (France). However, the situation is probably underestimated because most countries have inadequate environmental monitoring systems to safeguard their water resources. According to the World-Wide Fund for Nature (WWF) this is particularly the case in Belgium (Wallonia), France, Greece, Northern Ireland, Scotland, Spain and Turkey.

The loss of habitat is assumed to have strongly effected the capacity of the inland aquatic habitats to produce eels. Habitat destruction, loss of upstream accessibility, troubled escapement through turbines and deteriorated water quality all have had negative effects on local eel stocks.

3.3.1 Upstream accessibility of habitats

Loss of freshwater habitat due to construction of dams has occurred more in southern European countries than in northern countries (Moriarty and Dekker, 1997), reducing the potential eel production in these regions. On the Iberian peninsula, 70 percent of Portuguese and 93 percent of Spanish river habitats have restricted access for glass eel due to human intervention (dams without fish passages or contamination), including the largest river catchments (Ebro, Duoro and Tagus). Artificially restricted habitats not accessible to eels, mainly due to dams, include 50 percent of the Italian, 10 percent of the French, 5 percent of the Irish and 20 percent of the German rivers. Man-made impassable obstructions are almost absent in Great Britain and Sweden, dams being compensated with fish passages or upstream transportation.

The timing of construction of large dams in Europe coincided with the decline of European eel populations (Figure 9), with the largest number of dams built in southern countries (Spain, Turkey, Italy and France). The construction of new dams and water diversions could further reduce the availability of river habitats to eels unless they are supplied with proper eel passes. The installation of effective eel passes at dams could reclaim eel habitats from upstream catchments. The installation of a fish passage at the dam in the River Vilaine (Brittany, France) has resulted in fast colonization of the newly accessible habitat by naturally recruiting glass eels and an 2.8-fold increase in density of yellow eels (Briand and Fatin, 1999).

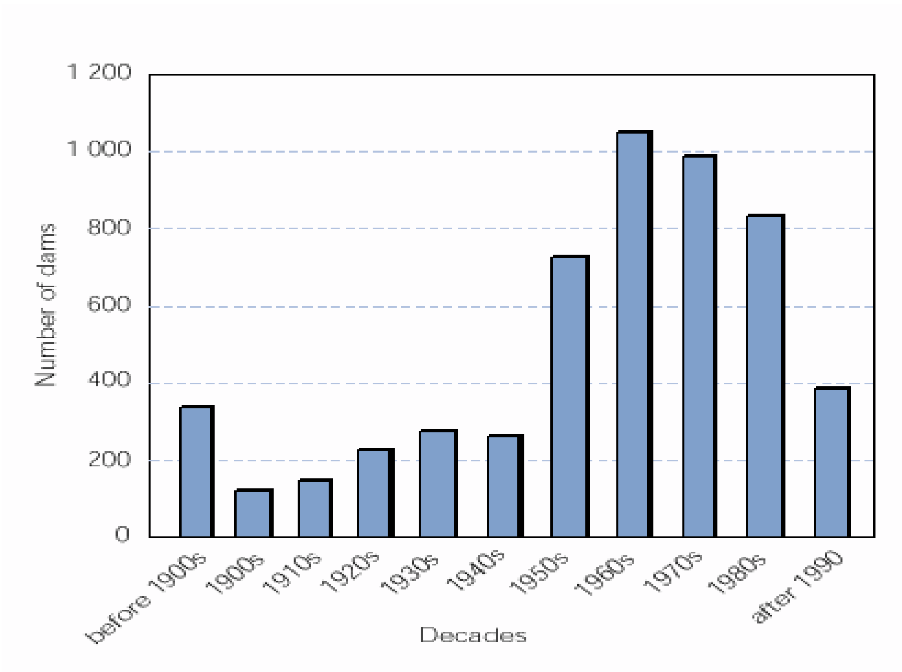


Figure 9. Number of large dams commissioned by decade in Europe. Data from ICOLD World Register of Dams (http://www.dams.org). Data for after 1990 is under-reported.

Impact of major dams is reported to restrict accessibility to upper reaches, but dams also modify habitat quality, transforming basically running shallow waters into deep still and eutrophic habitats. However, many major dams are not totally impassable as small eels may pass over wet vertical walls (Legault, 1994). Small dams, or hydraulic equipment such as bridges, pipes under roads, small weirs for irrigation, etc. often create temporary obstructions, and create a delay in migratory movements. Such conditions are assumed to increase mortality resulting in reduced eel stocks (Feunteun *et al.*, 1998). Impacts of obstructions have been reported for the Severn (UK) (Aprahamian, 1988; White and Knights, 1994, 1997a, 1997b), Thames (Naismith and Knights, 1988, 1993) and various smaller rivers in the United Kingdom (Turnpenny, 1989; Mann, 1995). A number of fish passes have been installed during recent years to facilitate the movements of eel and other riverine fish, but little has been done to monitor the efficacy of these structures. In the UK, three major tidal barrages have been constructed recently: at the mouths of the Rivers Tawe and Taff (S. Wales) and in the estuary of the River Tees (N.E. England). It is too early to say to what extent these obstructions may impact on the eel populations of these rivers.

There is currently no European synthesis on the number and location of minor and major dams and obstructions on river systems, but some regional examples might illustrate the impact of considerable river development and related impacts on upstream migrations of eels.

In France, in the River Rhone (100 000 km^2), there is about one hydrodam every 30 km on the main river. This has resulted in very low densities of eels in the river and no eels in most of the tributaries. Intensive re-stocking was conducted since the late seventies to sustain the riverine fisheries (Barral, 2001). Similar conditions are reported in the Seine catchment (89 000 km^2)and in international rivers such as rivers Rhine or Meuse.

Some large river systems such as the Loire (120 000 km^2) or the Gironde (100 000 km^2) are still not obstructed (about 300 km and 200 km from the tidal limit, respectively). However, the tributaries are highly developed for pleasure or commercial navigation and for flood control. For example, in the River Maine, a tributary of the Loire, there is about one dam or weir every 2 to 3 km (Feunteun *et al*., 2000b).

In downstream stretches (<20 km of the tidal limit) of 28 minor rivers of the French Mediterranean coast (including Corsica) a total of 62 dams were listed. A total of 66 percent of the hydraulic constructions reduce severely upstream movements, only 1.6 percent had efficient eel ladders (Barral, 2001). On the Atlantic, Channel and North Sea coasts, a high percentage of minor rivers are obstructed between the estuaries and upstream reaches.

Spain has the highest number of dams in Europe, with approximately 1 200 operating large dams. Fish passes exist at only 15 percent of dams in large rivers (Nicola, Elvira and Almodóvar, 1996). The existing fish passages are mainly concentrated in the North of the country and are designed for Atlantic salmon. In general, most Spanish fish passages are old, inefficient or non operative, making most dams effective barriers to upstream eel migrations (Nicola *et al*., 1996). Portugal has also been affected by the construction of dams starting in the 1950´s, and presently there are over 100 large obstructions and many more small dams. The existing fish passages are generally ineffective, poorly designed or non-functional and are the main reason for the disappearance of several migrating fish species (Valente, 1993).

In conclusion, most European river systems are highly obstructed by dams, weirs, and other constructions.

3.3.2 Destruction of habitat

During the 20th century, most European rivers and aquatic systems have been reconstructed intensively. Reconstruction policies were mainly aimed at developing agriculture, navigation, industrial and urban areas. The most affected areas are wetlands and secondary river channels which were subjected to destruction by either reclamation or dredging practices. Overall wetland losses exceeding 50 percent of original area have been reported by the Netherlands, Germany Spain, Greece, Italy, France and parts of Portugal (Jones and Hughes, 1993). Considering density dependant mortality, growth and emigration, the loss of wetlands is assumed to have reduced the available eel habitats in Europe by at least 50 percent. Currently, the habitat area is estimated at over 87 000 km^2 (Moriarty and Dekker, 1997).

A few case studies might illustrate the magnitude of the problem. Many major river systems in Europe, including the rivers Rhône, Rhine, Meuse and Seine, were heavily reconstructed between the fifties and the seventies to favour commercial navigation, hydropower electricity generation and flood prevention. As a result, most of the wetlands were drained and the secondary channels destroyed.

In the Rhône river, the flood plains and secondary river channels between Lyon and the delta (approximately 350 km) originally extended over an area of 1 to 3 km width. They have progressively been reduced to a 300 m wide channel with low habitat suitability for eels, resulting in a loss of 200 to 500 km^2 of freshwater habitats. In the Loire river, dredging has lowered the main channel by one to two meters over 200 km in the downstream reaches. Consequently, the secondary channels are now flooded only during a few days each year, resulting in a loss of 100 to 200 km2 of suitable habitats.

Coastal freshwater marshes of France cover about 250 km^2 of which 10 percent are aquatic habitats with a dense population of eels (50-150 g/m^2) (Feunteun *et al*., 1999). These have progressively been destroyed to favour agriculture but nowadays they are often abandoned. During the past decades, this situation was responsible for a rapid decline of the water surface by about 50 percent which now covers an area of about 10 km^2 (Feunteun *et al*., 1999).

If we only consider these three examples, it can be assumed that in France alone at least 300 to 700 km^2 of highly suitable habitats for eel have disappeared representing 12 to 28 percent of the 2 500 km^2 of freshwater bodies actually available. (Moriarty and Dekker, 1997).

Loss of habitat did result in a decrease of the eel stocks and a corresponding reduction in silver eel escapement. Therefore, habitat destruction must be considered as one of the major causes for the decline of European eel stock.

3.3.3 Downstream migration

Mortality caused by hydroelectric turbines is well documented. Direct mortality ranges between 0 and 100 percent according to site characteristics, generator system design and turbine management procedures. For example, Knösche, Zahn and Borkmann (2000) show that in large systems average turbine eel mortality is 28 percent. Many large rivers have a series of dams (up to 14 in the Rhône river). Therefore silver eels leaving downstream areas are exposed to the turbine mortality several times during their downstream migration. Therefore, even low mortalities at individual dams will result in high overall mortality rates for emigrating silver eel.

Water reservoirs also have an impact upon silver eel escapement. Most of the dams on reservoirs have not been designed to enable downstream migration. Passage through dams is often only possible through bypass tube systems, designed to produce minimum discharge releases. Induced mortality by bypass tube outlets as shown to be about 100 percent in a small river system of northern Brittany (Legault *et al*., in press).

Large dams are also assumed to delay downstream runs for up to several months, until maximal flooding conditions occur and overflowing of the dams occurs. The consequence of delays in downstream migration on the breeding success of eels is unknown.

In conclusion, obstruction to downstream migration and mortality caused by turbines are assumed to reduce silver eel escapement considerably. The overall impact is probably in the same order of magnitude as that of exploitation.

3.3.4 Water quality, contamination and breeding success

Reduced and deteriorating water quality has been reported in water systems all over Europe. Due to the improvement of management policies, in the past decade concentration of contaminants has decreased in many large river systems of Europe.

Contamination does rarely induce direct mortality in eels (Knights, 1997). However, a recent review (Robinet and Feunteun, 2002) shows that contamination, even at very low level, by PCBs, dioxin and organophosphorous pesticides, result in an inability to store lipids or a premature silvering. A number of lipophilic persistent contaminants are also suspected to be released in oocytes during maturation of females creating egg and larval mortality.

4 RELEVANT GEOGRAPHIC UNITS FOR MANAGEMENT OF EEL STOCKS AND FISHERIES

Management options discussed previously and below refer to whole-stock conservation limits which need to be translated into appropriate local-system targets. The European eel population shows limited genetic variation only at large geographical scales (Maes and Volckaert, 1999; Avise *et al.*, 1986; Avise *et al.*, 1990), but other characteristics of the stock vary at distances of few kilometres (Dekker, 2000a). Moreover, fisheries are generally organized at small to very small scale (Dekker, 2000a), with very little and mostly clinal geographical differentiation (Moriarty and Dekker, 1997). Neither biological characteristics of the stock nor structure in exploitation patterns provide a key to develop relevant geographical management units at reasonable scales. *The Working Group felt that management of eel should ideally occur primarily on a catchment by catchment basis.* The catchment unit should include all fisheries and other anthropogenic impacts that occur on an eel stock and should also assist in the maintenance of genetically distinct populations in the event that the species was found not to be panmictic. The catchment approach poses two difficulties for implementation:

1. many small watersheds exist for which no information on eel is available to fisheries managers, and
2. in large watersheds (e.g., the Rhine) several fisheries management jurisdictions are involved in the management of one eel stock.

It is therefore recommended to focus on jurisdictional entities (countries, regions, etc.), allowing for differentiation by life stage and by catchment area. This will entail:

- deriving appropriate targets from the best available catch (or effort) statistics and units of measurement available (e.g. see summaries in Moriarty and Dekker, 1997 and this report, Chapter 2);
- setting, applying and enforcing targets as appropriate throughout the jurisdictional area of fishery controls to achieve the overall limits recommended above;
- in areas where during their life cycle eels migrate through several jurisdictions, co-operation between the jurisdictions involved to meet the management objectives for this eel stock.

5 PRELIMINARY ESCAPEMENT TARGETS

5.1 Biological reference points and the precautionary approach

ICES has recognized that a precautionary approach should be applied to fishery management and that reference points are a key concept in its implementation (ICES, 2000). These reference points could be stated in terms of fishing mortality rates or biomass with the intention of ensuring that the stocks and their exploitation remain within safe biological limits. Implicit in the development of reference points is the assumption that there is a relationship between spawning stock and recruitment. The precautionary approach dictates that unless it can be scientifically demonstrated otherwise, such a relationship between stock and recruitment should be assumed to exist (ICES, 1997).

5.1.1 Reference points

The value of establishing reference points depends on the consequences to the resource of variations in spawning stock abundance. There are two hypotheses to consider in deciding whether spawning stock reference points are appropriate for the European eel; recruitment related to spawning stock size versus recruitment related to environmental conditions.

Consequences of managing for spawning stock size to future recruitment dependent upon the factor regulating recruitment

	Factor regulating recruitment	
Management approach	Spawning stock	Environment
Ignore spawning stock size	Risk of crashing the stock	Variable and unknown rate of recruitment
Manage for spawning stock size	Reduced risk of crashing the stock	Variable and unknown rate of recruitment

The prudent action under the conflicting hypotheses is to minimize the risk of crashing the stock. This would be achieved by assuming dependence of recruitment on spawning stock size, consistent with a *Precautionary Approach.*

There are two general classes of reference points:

1. Limits: set boundaries that define safe biological levels. Limits are often referred to as thresholds and are intended to minimize the risk of the stock falling below a minimum size (Mace, 1994; ICES, 1997).
2. Targets: are reference levels to aim for and are intended to meet management objectives such as achieving yields close to the maximum sustainable level (Mace, 1994).

Target reference points would be more conservative than limit points. Target mortality rates would be lower than the limit mortality rates whereas target spawner biomass reference points would be higher than limit spawner biomass levels. The management strategy would be designed to avoid exceeding the threshold and if the threshold is exceeded, then substantial reductions in mortality, including restrictions or prevention of the activity causing the mortality (for example fishing, turbine operation) would be considered (Rosenberg *et al.*, 1994).

Clear guidelines exist for the establishment and application of reference points (ICES, 1997):

1. A reference point is an estimated value derived through an agreed scientific procedure.
2. Both limit reference points and target reference points should be used.
3. Management strategies shall ensure that the risk of exceeding limit reference points is very low.

A large number of reference points (both mortality rates and biomass levels) and their associated data needs are summarized in ICES, 1997 (Table IX). The majority of reference points require information on several population parameters including age structure, growth, natural mortality, spawning stock size and recruitment size. The interpretation of some reference points versus a theoretical stock and recruitment relationship is shown in Figure 10.

The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points (ICES, 1997). To be consistent with the precautionary approach, limits should be defined in terms of mortality rates and spawning biomass levels (ICES, 1997).

There are advantages and disadvantages to the establishment and application of mortality rate limits and spawning biomass limits (Rosenberg *et al*., 1994).

	Mortality limits	**Spawning biomass limits**
Advantages	Relate directly to the activity that can be controlled	Biomass is directly linked to recruitment
	Can be estimated from relatively limited data and information on life history characteristics	Provide a guide for management of stocks that are already depleted
	Can prevent stock depletion due to the long-term activity	Provides a seed stock for eventual recovery when adverse environmental conditions constrain abundance
Disadvantages	Do not provide protection for stocks which are already at low level	Difficult and extensive data to collect
	May require modification if environmental conditions and life history characteristics change	Risk of mis-estimation when a limited range of stock conditions is available
		May be mis-interpreted as the point at which the resource will collapse

5.1.2 Consequences of uncertainty

The greater the uncertainties, the greater the need to be precautionary (ICES, 1997). Increased uncertainty renders optimal harvesting strategies more conservative and optimal threshold increases (Lande, Sæter and Engen, 1997). F_{lim} and B_{lim} are reference points that should be avoided with high probability. There are uncertainties in the estimation of F_{lim} and B_{lim} as well as uncertainties in the assessments of the resource status relative to population abundance and exploitation. As a consequence of uncertainty, ICES (2000) defined precautionary reference points (F_{pa} and B_{pa}) to constrain exploitation ensuring a higher probability of not exceeding the limits. F_{pa} and B_{pa} are the main devices in the ICES framework for providing advice (ICES, 2000). For European eel, the degree of uncertainty is extreme and this should be reflected in the setting of reference points.

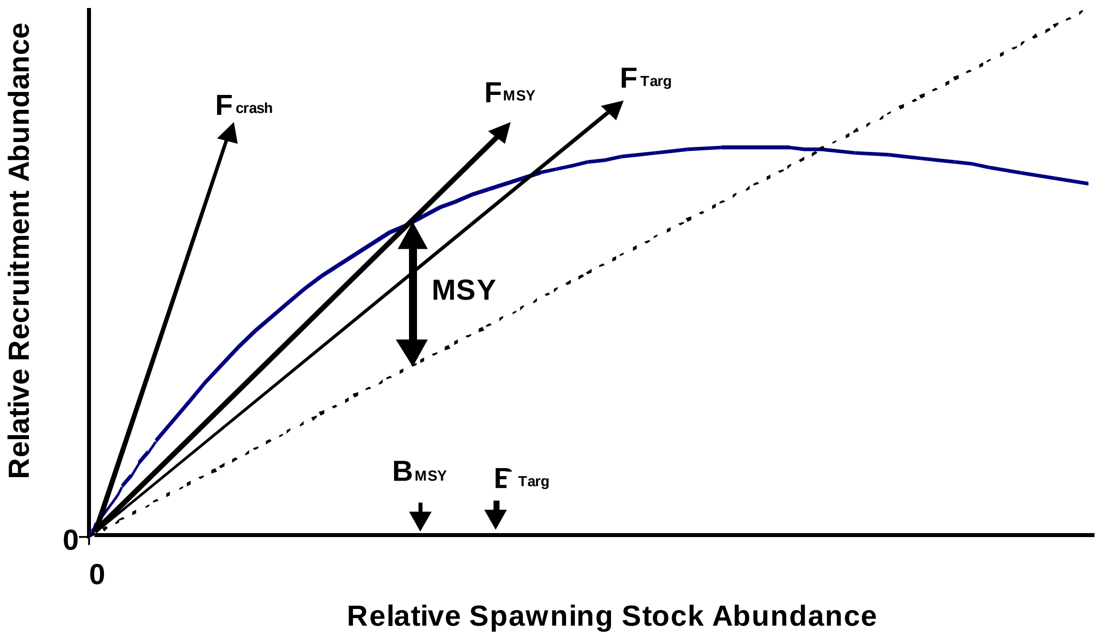


Figure 10. Position of some mortality rate and spawning biomass reference points relative to a theoretical stock recruitment relationship. The reference points are described in Table IX.

5.1.3 Proposed limit reference points in data-poor conditions

The majority of reference points require information on several population parameters including age structure, growth, natural mortality, spawning stock size and recruitment size. The limited knowledge and particular population dynamics of European eel are a major obstacle to the derivation of reference points. The wide distribution along the Atlantic and Mediterranean coasts of Europe and North Africa results in important differences in growth rates, age at maturity, and sex ratios. The mechanisms determining sex differentiation of animals are uncertain (growth rate, density, temperature, or a combination of factors). It is unclear how recruitment to freshwater occurs and whether there are regional stock and recruitment linkages. More important, there is little or no quantitative information on carrying capacity of habitat types for eels, or on what habitat variables determine carrying capacity. Natural mortality rates would vary with age and are likely to be high for the early life stages and decreasing with age and size.

Following the advice of ICES (1997), under data-poor conditions, a mortality rate which provides 30 percent of the virgin (F=0) SPR is a reasonable first estimate of F_{lim} until further information is gathered. Considering the many uncertainties in eel management and biology and the uniqueness the eel stock (supposedly single panmictic, spawning only once in their lifetime), a precautionary reference point must ultimately be more strict than the universal reasonable first estimate of F_{lim}. A preliminary estimate for F_{pa} could be 50 percent SPR.

Estimates of spawning stock and recruitment for the European eel are not available and are very unlikely to be feasible at all. Consequently, stock-wide management targets will have to be translated into derived targets for local management units (see Chapter 4). The number of water bodies for which adequate information is available to warrant local management on the basis of fully documented assessments is extremely limited. In the absence of such data, ICES, (1997) suggested that biomass index series such as CPUE series, harvest rate models, or survey-based measures could be used to establish relative B_{lim} reference points. For example, the maximum survey index could be used as an indicator of virgin biomass and B_{lim} would be some value of that maximum level, such as 20 percent of max. The estimate of B_{pa} could be set at a value higher than B_{lim}, i.e. 50 percent of the maximum of the index series.

5.2 Preliminary reference points for European eel

5.2.1 Reference values

Mortality rate method

Preliminary mortality rate reference points could be established across the entire species range. Any reference points established should consider the following:

- Given the difficulties in estimating and forecasting stock size, fishing mortalities should remain below M (natural mortality) (Walters and Maguire, 1996),
- Uncertainty in estimated population size increased B_{lim} (Lande *et al*., 1997),
- Ability to monitor compliance.

Overall loss to spawning stock depends upon the number of years eels are vulnerable to the fishery. Reference exploitation rates would vary with region – higher in the south than in the north.

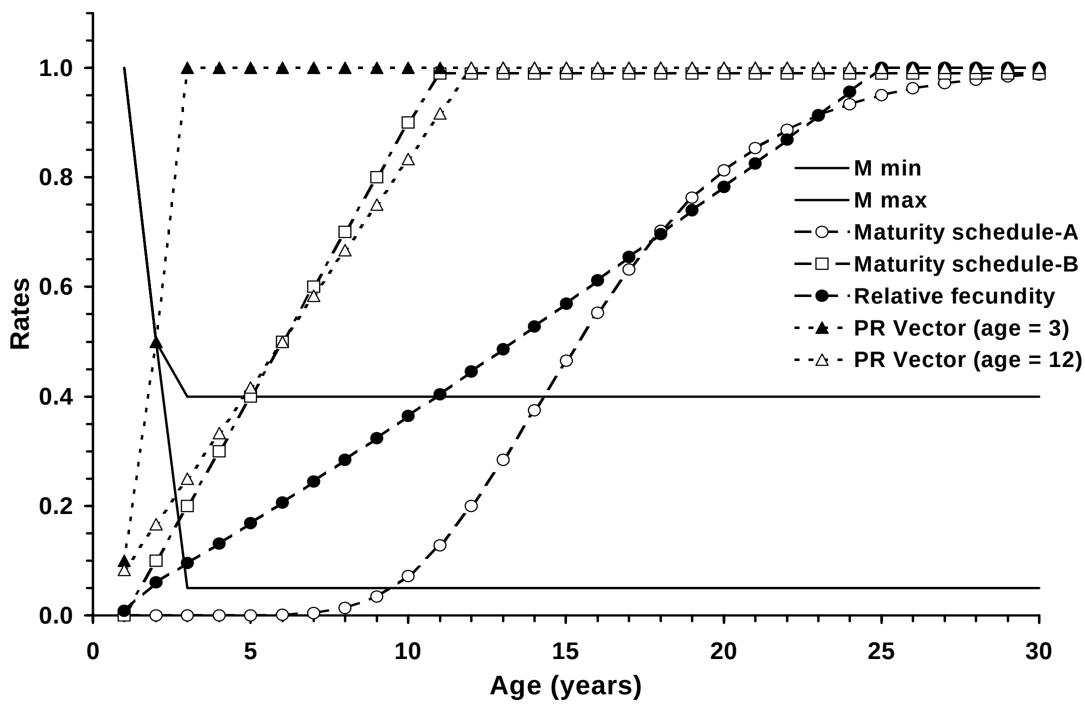


Figure 11. Input assumptions to the spawner to recruit modelling to estimate F_{lim} and F_{pa}. Maturity schedule refers to the proportion of the potential female yellow eels destined to metamorphose to silver eels. PR vector refers to the partial recruitment vector to the fishing gear. Maturation schedule A refers to a northern area stock and schedule B would be representative of a southern area stock.

Preliminary values of F_{lim} were derived from a theoretical recruit to spawner analysis (ICES, 2001) and provisionally determining F_{lim} at the F that generated 30 percent SPR. F_{pa} was estimated from the 50 percent SPR profile. These mortality reference points are estimated for eels aged one year and older. They could be calculated to include the recruiting stage but consideration for density-dependent regulation at the recruiting to yellow and silver eel stage would have to be considered.

The maturation schedule of eels is not well known, but female silver eels in northern areas are on average older than in the south. The same is true for male eels. Some representative maturation schedules were examined to see the effect of these on the SPR solutions (Figure 11). Simple partial recruitment vectors considered in the example calculations assumed full and constant recruitment at a given age (3 years or 12 years).

An example calculation estimating F_{lim} and F_{pa} for eel with variable maturation schedules probably typical of northern area and southern area stocks is shown in Figure 12. The percent SPR function is relatively insensitive to the natural mortality assumption (as seen by the width of the crescent profile) for the northern area assumptions but was more important for the southern area. F_{lim} to F_{pa} range was narrow (between F = 0.06 and 0.12) for the northern area stock and wider (between F = 0.11 and 0.32) for the southern area stock (Figure 12). The maturation schedule is particularly important in the estimation of F_{lim} and F_{pa} as this determines the number of years the animal is exposed to the fishery.

The reference points are also sensitive to the partial recruitment vector assumption. The partial recruitment profile would respond to management actions such as size limits on retained eels, mesh size limits, area restrictions, and seasons. In the second example, the effect of different partial recruitment vectors (fully recruited at age 3 years versus fully recruited at age 12 years) (Figure 11) but for a fixed maturation schedule (northern profile) is described. The F_{lim} and F_{pa} points increase as the age of full recruitment to the fishery increases.

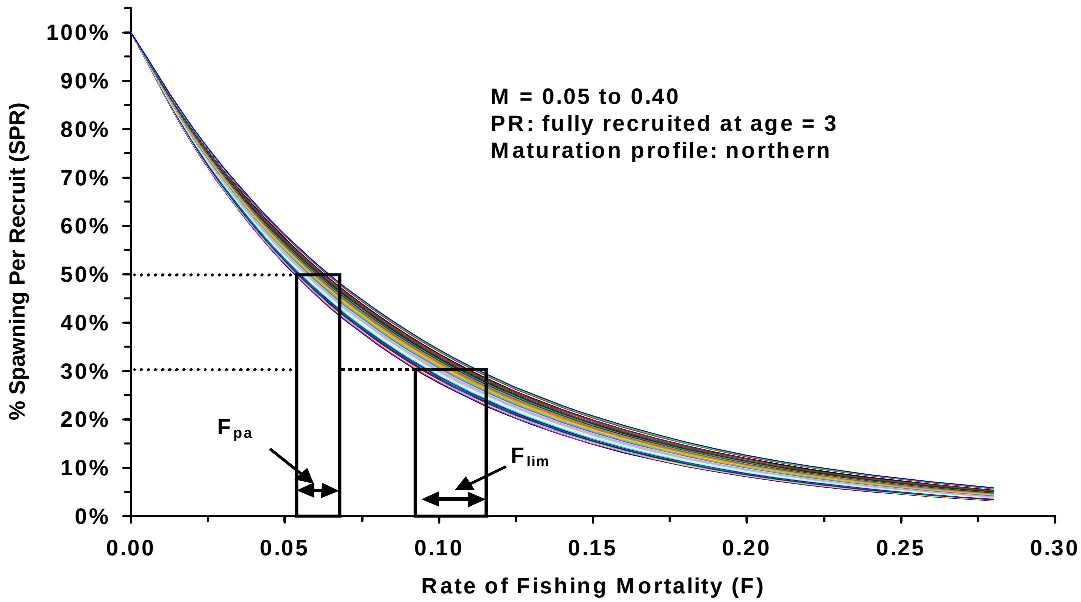
Biomass method

No precedent exists for the setting of biomass SSB limits for eel. However, the method is an accepted method of assessing marine fish stocks, along with known or estimated SSB to recruitment relationships.

Most European eel producing areas are extremely data-poor, with insufficient data for stock assessments based on standard methods. Thus, other means of formulating reference points are required, at least *ad interim*, until data sufficient for the practical implementation of traditional stock assessment methods become available.

A provisional limit reference point is therefore proposed based on the contribution of individual catchments to the spawning stock relative to the notional biomass of an unfished stock in an environment with no negative human impacts, such as habitat loss or degradation and mortality to spawning migrants during downstream passage through power generation turbines.

The carrying capacities of freshwater habitats for European eel have been reviewed by Moriarty and Dekker (1997) who assumed an average of 10 kg/ha. This value could be used as a benchmark value, with a proportion assigned as an initial reference level for the minimum silver eel escapement for each catchment or chosen geographical area. However, the best habitats can produce 40 kg/ha or more and there is a south-to-north decrease in potential silver eel production. Thus, the potential minimum output from rivers in the Mediterranean region decreases from about 40 kg/ha, through 20 kg/ha along the continental Atlantic coasts, to 10 kg/ha in the southern North Sea and British Isles, and to about 5 kg/ha in the Baltic and Swedish/Norwegian rivers. Escapement conservation limits would be set as a proportion (e.g., 30 percent) of these regional potential production figures rather than of the European average value. The primary management objective would therefore be to ensure a high probability of maintaining the spawning escapement above these limits.



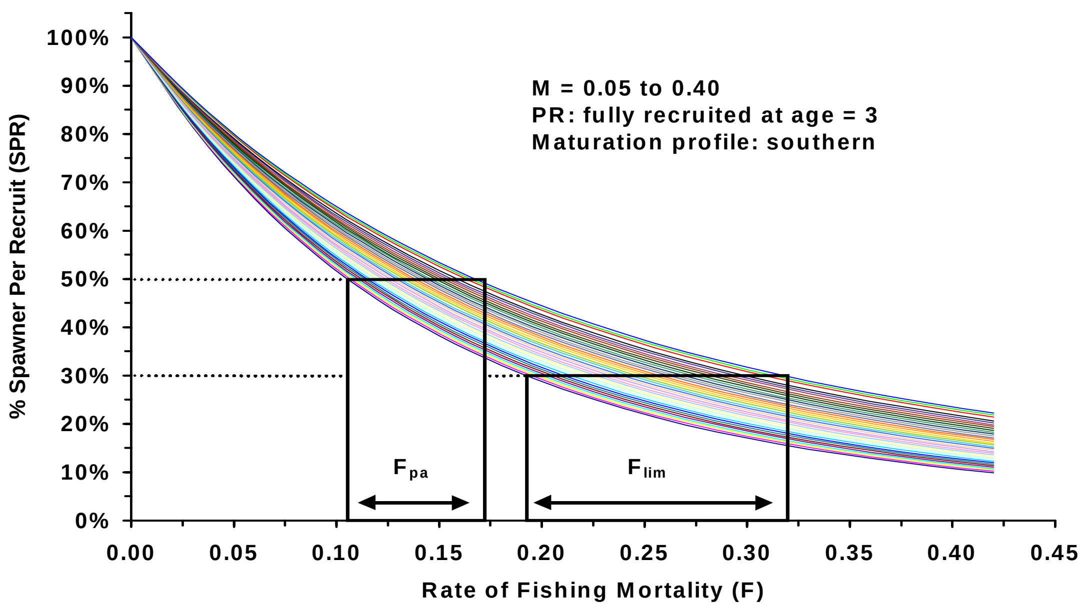


Figure 12. Estimated percent SPR relative to F for the eel stock of the northern area (upper panel) and a southern area (lower panel) for varying assumptions of M. The estimated percent SPR is eggs per R (adjusted for fecundity at length).

Dekker (1999) estimated a Europe-wide spawning escapement limit reference value of 23 to 33 percent of potential unexploited spawner biomass. Setting the conservation limit at

30 percent of potential unexploited spawner biomass would ensure that spawning escapement is sustained. The threshold level is expressed as a percentage of the level that would occur if there was no fishing and is referred to as the 'threshold replacement percent SPR'. For species for which very limited stock-recruitment data are available it may be appropriate to set a threshold replacement percent SPR of 30 percent. The conservation limit proposed is more risk averse than a 30 percent SRP. This is because the conservation limit is based on the ratio of two biomass (or stock) levels, while the percent SPR is based on the ratio of two spawner-per-recruit levels. If recruitment is not substantially reduced when the spawning stock level is reduced to 30 percent of the unexploited level, then an escapement of 30 percent will be equivalent to a percent SPR of 30 percent. If, however, the recruitment is reduced, then an escapement of 30 percent will translate into a percent SPR greater than 30 percent.

Length-frequency distribution reference point

Length-frequency distributions are perhaps the most common of eel data sets. They offer the possibility of a simple reference point related to the numerical proportion of potential emigrants. The fishing of yellow eels tends to crop the larger individuals, resulting in size distributions skewed towards smaller eels. This suggests the possibility of estimating fishing mortality, biomass reduction, SPR reduction, or other effects of fishing from length-frequency analysis. In principle, an arbitrary limit reference point can be proposed, e.g., that 50 percent of eels should exceed 50 cm and thus be potential spawners. This approach has the advantage that it would result in collection of data that could enable year-to-year refinement of life table models and could ultimately lead to mathematically-based escapement estimates. However, no length-frequency distribution reference point can be recommended at this time because of insufficient testing of the method.

5.2.2 Limitations of methods

Limitations of F_{lim} method

The estimates described above are based on equilibrium conditions, i.e. no change in characteristics with abundance. Adding stock and recruitment to the model has an effect on yield calculations, i.e., yield declines with increasing spawning stock size (Hilborn and Walters, 1992). Defining only F_{lim} reference levels can be dangerous because an F-based definition appropriate over a middle range of biomass levels may not be appropriate at the extremes of biomass. Also, the definitions set to prevent long-term decline of the stock do not increase the protection to the resource when it is in poor condition (Rosenberg *et al*., 1994).

Limitations of the biomass method

There are undeniable problems in setting a reference point based on a proportion of the SSB expected for any given system in the absence of fisheries and other deleterious impacts. The central problem is the definition of pristine habitat and estimation of biomass under unfished conditions. Most eel producing freshwater systems have suffered habitat reduction or degradation in habitat quality. Thus, the starting point should be based on full utilization of currently available eel habitat. The provision of access to additional eel habitat upstream of barriers is a practicable option for increasing SSB outputs in many systems. Most eel stocks of reasonable abundance are also fished and the stock structure and biomass available under unfished conditions may be difficult to quantify.

The second problem encountered is in measuring output. This imposes a requirement for field study monitoring. Some freshwater fish stock monitoring of resident fish stock biomass, including for eel, will be required under the EU Water Framework Directive. This, in conjunction with length-frequency data or age profiles, and known proportions of emigrants based on the results of some current field programs (in France) could form the basis of estimating individual system escapement of SSB in the near future. Where large-scale fisheries for silver eel still exist, mark-recapture programs offer another means of assessing SSB escapement.

Generation of the data series to allow adoption of this method to eel stocks will take many years. The co-ordinated development of an annual combined European SSB time series and continuation of existing recruitment time series would eventually allow the examination of SSB to recruitment relationships.

Limitations of the length-frequency distribution method

Problems with the length-frequency distribution method include the known naturally downward skewed size distributions from electrofishing data in shallow streams and, in some cases, in lower reaches of rivers. Length-frequency distributions can also be temporarily skewed downward by recruitment of a strong year class. Natural variations in recruitment may also mask biomass changes due to fishing pressure. The measured populations are also assumed to have no immigration or emigration during the continental juvenile phase. Different applications of the method may require data such as a time series of measured abundance, the length frequency distribution and age of the stock, and data on the unexploited stock.

5.2.3 Application of limit reference values

Application of F_{lim} and F_{pa}

The estimation of F_{lim} and F_{pa} levels applicable to a stock are dependent upon information on the age and size composition, maturation schedule, and characteristics of the fishery itself including size selectivity and availability of life stages to the gear.

When the mortality factors on the stock are managed such that F equal to or less than F_{pa}, there should be a low probability that the realized mortality is not sustainable (ICES, 1997). In the absence of B_{lim} and B_{pa} reference points, other measures of stock status would be used to assess compliance with the limit and PA points. These indicators would include size composition of the catch relative to unexploited areas, relative abundance of yellow and silver eels (when these are available for capture), condition factors, etc.

Application of the biomass method

The biomass method has not yet been applied to a specific eel stock. Application of the method depends on developing an acceptable definition of pre-exploitation available habitat and of the biomass produced under those conditions as well as an estimate of current biomass under existing fishing conditions. The target and limit biomass levels appropriate to eel stocks require further development. For the meantime, a target biomass level is proposed of 30 percent of the unexploited biomass level.

Application of the length frequency distribution method

A simulation model for New Zealand eels by Francis and Jellyman (1999) found that only large (>40 percent) changes in biomass could be detected by shifts in mean size. A stochastic life table model (see Chapter 7.2) may be used to track cohort strength and demographic factors between glass eel arrival and egg deposition. This model differs from the Francis and Jellyman (1999) approach in that the slope of the right-hand limb of the length-frequency curve was used to infer stock parameters. Simulation results showed that recruitment variation strongly affected the frequencies of smaller eels but had little effect on frequencies of larger size classes.

The model requires a length-at-age table, an equation relating length and weight, and the length frequencies of unexploited and exploited populations. It can be used to estimate fishing mortality and summed natural mortality/emigration. The plot of the relation between fishing mortality and percent reduction in spawn output per recruit (SPR) allows determination of the fishing mortality that corresponds to a given SPR-based conservation reference point. In this model, SPR is defined as the reduction of egg deposition due to fishing. Where fecundity-weight relations are unknown, SPR reduction could be modelled in terms of biomass of emigrating females.

This model permits estimation of key demographic parameters and evaluation of compliance with conservation reference points using relatively modest data requirements (lengths, weights and ages). The model examined in Chapter 7.2 found the slope of the descending right-hand limb of the length frequency distribution was about 3 times steeper for a relatively heavily exploited population than for an unexploited population. The slopes of the length frequency distributions of presently exploited stocks may be indicators of exploitation status.

5.3 Conclusions

Essentially, there are two possible approaches by which spawner escapement targets might be set for European eel in specific river systems:

1. mortality limits
2. spawning biomass limits

In reality, most systems have insufficient data on which to set escapement targets based on either of these two. Only the few data rich systems can allow ready implementation of any limit reference value. In the long term, mathematical models may be developed for the total stock based on individual monitoring of its components, and the methods chosen now to set limits should encourage the collection of the necessary data and to derive proximate criteria for data-poor environments.

Provisional targets needed and developed now will necessarily be based on a very high degree of uncertainty in the available data. Provisional targets must be workable in extremely data-poor systems and will have to permit a high degree of local management flexibility.

Thus, the only possible basis for immediately applicable escapement targets may be biomass limits set as a percentage of the theoretical pristine silver eel outputs for major river systems or groups of river systems. The initial target proposed is 50 percent of this theoretical production level. The theoretical pristine production figure must eventually be set on a local or regional basis. Additionally, limits based on length composition of the catch can be applied, but these limits are currently still highly arbitrary.

Implementation of stock monitoring to define pristine condition spawner outputs requires fish population surveys for length/age frequency distribution, sex ratios, and abundance/density estimates. These data, in conjunction with present and continuing time series of eel recruitment and production will, if systematically gathered across the range of the eel, lead to development of better models of eel population dynamics and stock-recruitment relationships.

It is important to note that EU member states will soon be required, under the Water Framework Directive currently being implemented, to gather much of this data and to use it to assess habitat condition relative to a notional pristine or reference condition.