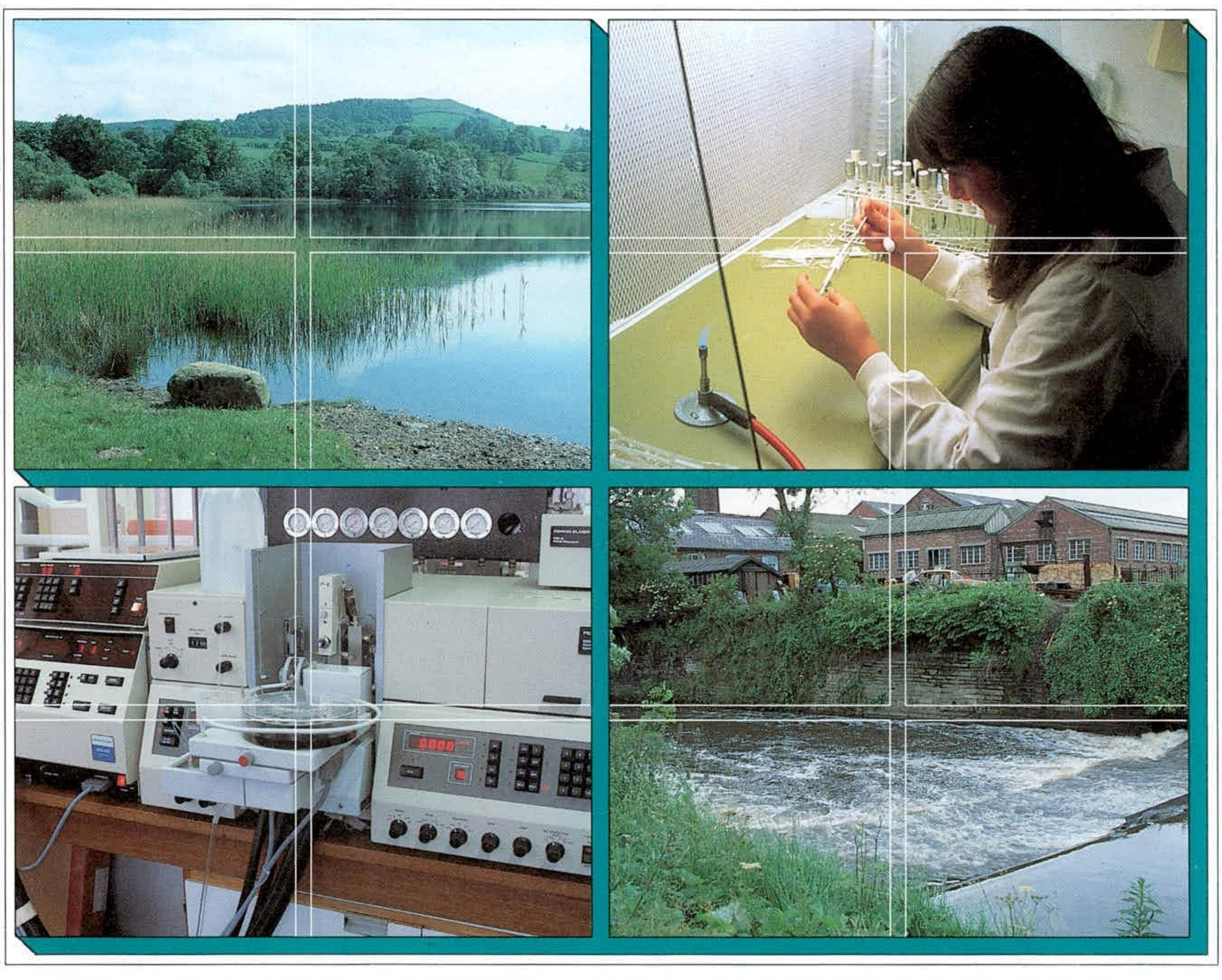
Institute of Freshwater Ecology

Eel Stock Assessment in the UK

R.H.K.Mann & S.J.Welton



Natural Environment Research Council

EEL STOCK ASSESSMENT IN THE U.K.

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March 1995

MAFF Project Number: SF0305
IFE Project Number: T11063a1

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ACKNOWLEDGMENTS

Many people have been extremely helpful in running this project.

Numerous N.R.A. staff in the 8 Regions provided essential information on eel catch data in their areas, and on local eel management policies. Dr C. Moriarty (Dublin), the secretary of the EIFAC *Working Party on Eel* provided several important references.

Within I.F.E. I am particularly grateful to Mr G. D. Collett for help in collating much of the NRA data, and to Dr I.Winfield for providing access to some of the Lough Neagh information.

EXECUTIVE SUMMARY

1. The European eel forms a single stock, the adults of which spawn in the Sargasso Sea. From here, the Gulf Stream transports the young eels (leptocephali) across the Atlantic Ocean to the coasts of Europe and the Mediterranean.

2. It is supposed that there is random mixing of the young eels entering European fresh waters and of the adults returning to the Sargasso Sea. Genetic studies are needed to confirm this, but is clear that optimum management of stocks requires international co-operation.

3. There are few accurate estimates of eel population densities in U.K. waters. Most are derived from general fish surveys in which the eel was not the principal target species. The number of estimates of eel numbers greatly exceed those of eel biomasses. Population densities in most waters are generally less than 5 eels per 100 square metres (500 per hectare).

4. Age determination of eels is difficult and the results are often equivocal. The standard methods of age determination recommended by the EIFAC *Working Party on Eel* need to be applied routinely to U.K. eel populations.

5. Eels can pass upstream over small weirs, but large weirs and vertical barriers inhibit their migration. The Severn-Avon is the only U.K. river system in which there is a policy of eel pass construction, although passes exist in the Thames catchment and on the River Nene. A proposal to construct passes in the Thames catchment is under review.

6. Recommendations for further studies of U.K. eel populations are outlined, the most important being:
   - estimates of eel stock densities in a range of rivers
   - determination of age structure of commercial catches of yellow and silver eels.
   - assessment of the impact of restricting migration on the numbers of female eels

1. INTRODUCTION

1.1 *Background and aim of the study*

Since the early 1980s, decreases have been observed in the numbers of glass eels caught at several locations around the coast of Europe, and in the numbers of elvers caught as they move into rivers. In 1993, a meeting of the EIFAC *Working Party on Eel* focused on the widespread concern in Europe of the effects of poor recruitment, especially the impact on eel fisheries.

This concern arose because low recruitment had lasted for a period equivalent to the average life-span of a mature eel in the northern part of its range. Thus, a fall in stock levels, induced by poor recruitment, could generate an increased downward trend in future recruitment because fewer mature eels would be returning to the Sargasso Sea to spawn.

However, the EIFAC meeting noted that despite this grave concern for the continued existence of the fisheries and the welfare of the fishermen, the prospects for stock enhancement and development of European fisheries were excellent. But they also noted that major steps in management leading to enhanced fisheries had not been taken on a European-wide basis.

Suggestions as to the factors causing a decrease in the numbers of glass eels and elvers approaching and entering European rivers include:

a) natural variations in oceanic conditions affecting the transport of leptocephali from the Sargasso Sea,

b) commercial overfishing,

c) loss of riverine habitatthrough the effect of barriers on the upstream migration of juvenile eels,

d) chemical contamination of eels at various life-history stages,

e) the effect of the swim-bladder parasite *Anguillicola crassus* (Nematoda) on the migration of silver eels to the Sargasso Sea.

Few accurate data on the status of U.K. eel stocks exist despite the widespread distribution of the species in U.K. fresh waters. Lack of appropriate information on the stocks of eels during their various developmental stages (elver, yellow (brown) eel, silver eel) will render management decisions regarding eel stock management difficult, and most will be based on subjective assessments.

The **OBJECTIVE** of this report is to collate current information on U.K. eel stocks with reference, where appropriate, to studies of stocks in mainland Europe and Scandinavia. Reference is also made to the American eel, *Anguilla rostrata* (LeSuer), which has also suffered from decreased elver recruitment, particularly in the northern part of its range.

Throughout the report, references to eels or elvers relate to the European eel *Anguilla anguilla* (L.) unless otherwise stated.

1.2 *Homogeneity of the European eel stocks*

Based on the early works of Schmidt (1923), the European eel, *Anguilla anguilla* (L.), is usually regarded as forming a single panmictic stock, the adult members of which all spawn in the Sargasso Sea. The resulting leptocephali are thought to be transported passively by ocean currents towards Europe and the Mediterranean coasts, the journey taking about two years.

This concept has been challenged recently by Lecomte-Finiger (1992, 1994), who suggested that the eels approaching Europe are less than one year old. If this is true, then the leptocephali and/or glass eels are swimming more actively than hitherto thought, or else they are using some form of selective tidal stream transport. It is clear that, until more studies are made, the mechanisms and duration of transport of eel leptocephali in the north Atlantic will remain an enigma (McCleave, 1993).

There is some evidence of morphological differences (e.g. total number of vertebrae) between elvers from different geographical locations, although these may arise from local environmental influences (Sinha, 1967; Harding, 1985). However, more information on the genetic make-up of eels throughout their distribution is needed to test for the existence of separate eel stocks. Marked geographic variation in eel growth and age at migration have also been demonstrated, but the data are not sufficient to demonstrate if this phenotypic plasticity is adaptive (Vollestad, 1992).

The present consensus is that the catadromous, panmictic life style of the European eel prevents any long-term adaptation to local conditions. If this true, then all countries have a responsibility to maintain and enhance their own populations for the general good of all countries. The concept of subsidiarity within the European Community countries has no part to play in this context.

1.3 *Sources of data*

Information on the European eel in general, and of U.K. stocks in particular, is widely dispersed and data were collected from several sources:

a) Scientific publications: Over 160 publications were examined from a list of over 260 titles, including many from the meetings of the EIFAC *Working Group on Eel.*

b) NRA fish survey reports: Details of eel catches from electrofishing and netting surveys carried out by the NRA Regions and their predecessors were collected, either as typed internal reports, summaries extracted from handwritten notes, or computer databases.

c) Unpublished PhD and MSc theses.

d) Unpublished data from rivers in southern England collected by the IFE (previously the Freshwater Biological Association).

e) MAFF reports on commercial eel catches.

f) Commercial catch statistics from the NRA regions and the private sector.

In addition to the information presented in this report, there are two other important publications regarding U.K. eel stocks:

C.P.Morrice (1989). Eel fisheries in the United Kingdom. MAFF Internal Report No. 18.

E.M. White & B. Knights (1994). Elver and eel stock assessment in the Severn and Avon. NRA R&D Project Record 256/13/ST.

1.4 *Eel distribution in the U.K.*

Eels occur in almost all natural water courses in the U.K., the exceptions being upland waters where access is denied by impassable falls (e.g. some Pennine streams: Turnpenny, 1989). Although eels are more resistant to the adverse effects of low pH than salmonids (Alabaster & Lloyd, 1980), a survey of 181 upland streams in the U.K. (Turnpenny, 1989) showed that population numbers are generally lower in acid waters (low pH) (Table 1).

TABLE 1. Percentage occurrence, population density and biomass of eels in 181 U.K. streams in different pH categories. Maximum values (max.) = means + 95% confidence intervals. Values read from histograms in Turnpenny (1989).

pH		<5.1	5.1 -5.5	5.6 - 6.0	6.1 - 6.5	>6.5
No. of streams with eels (%)		27	30	43	63	67
No. m^{-2}	mean	0.03	0.02	0.10	0.08	0.08
	max.	0.06	0.05	0.20	0.12	0.17
g m^{-2}	mean	1.04	0.90	3.74	2.08	3.46
	max.	1.66	2.22	7.67	3.69	6.53

Low densities also occur in water courses with artificial barriers (weirs, sluices, locks) which, though not necessarily impassable to eels, inhibit their upstream migration.

A few water courses enter the sea through piped outfalls (e.g. River Hundred, Norfolk) or via gravity flaps (e.g. some Lincolnshire drains). On the River Witham, Lincolnshire, sluices near the sea at Boston are closed at high tide and then opened at low tide to allow fresh water to escape (Coles, 1979). Waters such as these also contain low population densities of eels upstream of the barriers.

2. ELVER RECRUITMENT

2.1 *Evidence for a decline in eel recruitment*

The data on the decline in numbers of glass eel and elvers caught annually since about 1980 are from both U.K. and overseas sources (Table 2). Some of the results may be affected by changes in fishing intensity, though the variations are probably not very large at any single site.

The results indicate that the decline started in the early 1980s, although there are some differences in its onset between sites. As noted by the EIFAC *Working Party on Eel* (Moriarty, 1986), physical conditions such as weather, temperature, and stream current velocity can affect elver recruitment. Such impacts reduce the value of elver catches as indicators of breeding success in the Sargasso Sea, or of the survival of leptocephali during their trans-Atlantic migration.

Is the downward trend in elver numbers continuing ? Some encouragement over the situation comes from Moriarty (1994), who hints that an improvement in stocks may have started. There has been a substantial increase in the elver catches in the Loire (France) from a minimum of 30 tonnes in 1991 to 95 tonnes in 1994. Although this is far short of the peak catch in 1976 of 770 tonnes, a slight increase has been observed in 1994 in the Viskan, Erne, Shannon and Yser, and also in the catches of the American eel, *A. rostrata*, in the St Lawrence river. However, the catches of *A. rostrata* are not strictly comparable, because the eels had a mean age of four years when they reached the catching station, which was 750 km upstream of the Gulf of St Lawrence.

These data are inconclusive, and continued monitoring at all of the elver catching stations (Table 2) is essential to provide data on long-term trends in abundance. The monitoring of the catches by elver traps on the River Severn (and possible the River Nene) will be valuable adjuncts to such information.

TABLE 2. Five year means of glass eel or elver catches at the mouths of 10 European rivers. Values are metric tonnes, except for the DenOever site which are abundance indices, based on dip net samples. The data are taken from Lara (1992) and Moriarty (1986, 1990a, 1994). Parentheses indicate incomplete data sets.

Location Country	DenOever Netherlands	Loire France	Ems Germany	Nalon Spain	Bann N. Ireland
Year					
1941-45	-0.36	(32)			
1946-50	-1.24	139	1.15		
1951-55	0.04	129	3.13	(13.3)	
1956-60	-0.16	234	3.83	14.7	
1961-65	1.22	182	3.92	15.4	0.93
1966-70	0.27	380	1.62	17.0	0.89
1971-75	0.38	398	2.23	27.0	(0.58)
1976-80	0.69	611	3.24	42.4	0.53
1981-85	-0.28	231	0.47	19.4	2.74
1986-90	-0.44	101	0.02	2.0	2.96
1991-94	-1.05	59			1.63

Location Country	North Sjaelland Denmark	Vidaa Denmark	Minho Portugal	Viskan Sweden	Shannon Eire
Year					
1971-75	(4.89)	0.71	(6.1)	0.78	
1976-80	5.77	0.34	30.02	0.49	(3.40)
1981-85	4.80	0.30	30.7	0.28	1.51
1986-90	3.45	0.12	8.6	0.09	0.64
1991-94			7.8	0.05	0.15

2.2 *Reasons for the decline in eel recruitment*

The decrease in elver catches has occurred generally throughout Europe and, although individual catchments may have local problems, a more general explanation for the phenomenon has been sought by various researchers.

Chemical pollution, habitat modification, overfishing and oceanographic changes were examined by Castonguay *et al.* (1994a, b) as possible causes of the declining recruitment of the American eel, *A. rostrata.* They noted that *A. rostrata* recruitment has declined dramatically in parallel with that of *A. anguilla.* As both species spawn in the Sargasso Sea, the authors concluded that the coincidence in recruitment failure implied an Atlantic-wide cause. There is some evidence that the Gulf Stream has slowed since the 1980s, which could explain the observed decrease in abundance in the northern part of the range of the American eel and the more uniform decreases in European eel recruitment.

Although this argument has found support (e.g. White & Knights, 1994) the specific causes of recruitment decline remain unclear. It is certainly possible that oceanographic changes are implicated, but also that changes in local conditions have aggravated the problem in some rivers.

3. ELVER MIGRATION

3.1 *Seasonal variation*

The seasonality in the peak numbers of elvers migrating upriver has been known for centuries, and there are numerous references in the scientific literature. Glass eels arrive off the coasts of Europe during the winter and early spring. For example, the peak months for the commercial capture of glass eels off the coast of Asturias (northern Spain) are from December to February. (Lara, 1992).

Entry of elvers into most rivers, including U.K. rivers, usually starts in the spring, with the period of peak migration normally taking place during the early summer months. Peak times can vary between years and between sites. At DenOever (Netherlands), most eels attempt upstream migration during April, whereas May is the preferred month in the Vidaa (Denmark) and June/July in the Shannon (Eire).

In the River Frome, Dorset, the peak run over a flume c. 12km above the head of tide occurred in late May/early June (R.H.K.Mann, unpublished data). The run comprised elvers that had just entered the river, together with larger, older eels that had entered the river in previous years (Table 3).

TABLE 3. Length-frequency distribution of migrating eels caught on the East Stoke flume, River Frome, Dorset on 9 June 1964.

Length (mm)	No. of fish	% Number
70 - 74	13	5.7
75 - 79	44	19.2
80 - 84	69	30.1
85 - 89	44	19.2
90 - 94	21	9.2
95 - 99	13	5.7
100 - 104	5	2.2
105 - 109	6	2.6
110 - 114	4	1.7
115 - 119	3	1.3
120 - 124	5	2.2
125 - 129	0	-
130 - 134	0	-
135 - 140	2	0.9
Total number	229	

Upstream migration commences in April in the Thames catchment and continues until October, but the majority of young eels migrate over a distinct period (ca. 47 days) in May-June (Naismith & Knights, 1988). The actual timing varies between years and commencement appears to be dependent upon water temperature. The number of unpigmented elvers entering the estuary also varies from year to year, although most elvers seem to spend at least one year in the Thames estuary.

As has been found in other large rivers (e.g. River Severn: Aprahamian, 1986), eels can take several years to reach the upper catchment. Thus, in the Thames, the mean size and age of migrants increases upstream from under 14cm (1 to 3 years old) when leaving the estuary to 20 to 30cm (4 to 8 years old) some 15km upstream.

The stimuli for migration to commence appear to be a combination of meteorological and hydrographic factors. For example, Ezzat & El-Serafy (1977) noted that the run of elvers in the Mex Canal, Egypt started at the end of February and continued through June, with peak numbers arriving in April-May. Most elvers entered the canal at pH 7.7 to 8.0 and within a water temperature range of 20-25°C. There was a slight increase in the mean size of elvers towards the end of the migration period (e.g. in 1972 this was from c. 60mm in March to 70-75mm in April/May).

Other authors have also shown the importance of water temperature as a stimulus to migration and Section 3.2 summarises the principal results.

3.2 *Water temperature*

A range of critical temperatures to stimulate upstream migration has been recorded by various authors. Mann (1963) observed that 17 to 22cm eels in the River Elbe, Germany started their upstream migration at 8 to 9°C, but most moved at ca. 22°C. Migratory activity was reduced if the water temperature decreased, and most eels were found to move at night (Mann, 1961). In a review, Tesch (1977) noted that 6-8°C was enough for migration to start in some waters, but in the River Imsa, Norway, 11°C was the threshold temperature (Hvidsten, 1985a). In this river a strong correlation was recorded between elver catch (recorded as volume of eels: one litre = ca. 2100 glass eels) and river temperature (Figure 1).

Water temperature also appears to be implicated in the movement of glass eels/elvers as they find their way from coastal waters into rivers, but the mechanisms are complex. Tongiorgi *et al*. (1986) found experimentally that the thermal preference of glass eels changes in relation to different environmental conditions. In long-term experiments in still water (analogous to most conditions at the start of the juvenile eel's trophic post-migratory phase) thermal preferences were close to the optimum growth temperature of the species, 20-25°C (Sadler, 1979). In flowing water (comparable to the conditions that glass eels experience during their ascent phase) preference was for temperatures at or below the temperature to which they were acclimated. Only at very low temperatures (3-9°C in the experiments) were the preferences inverted.

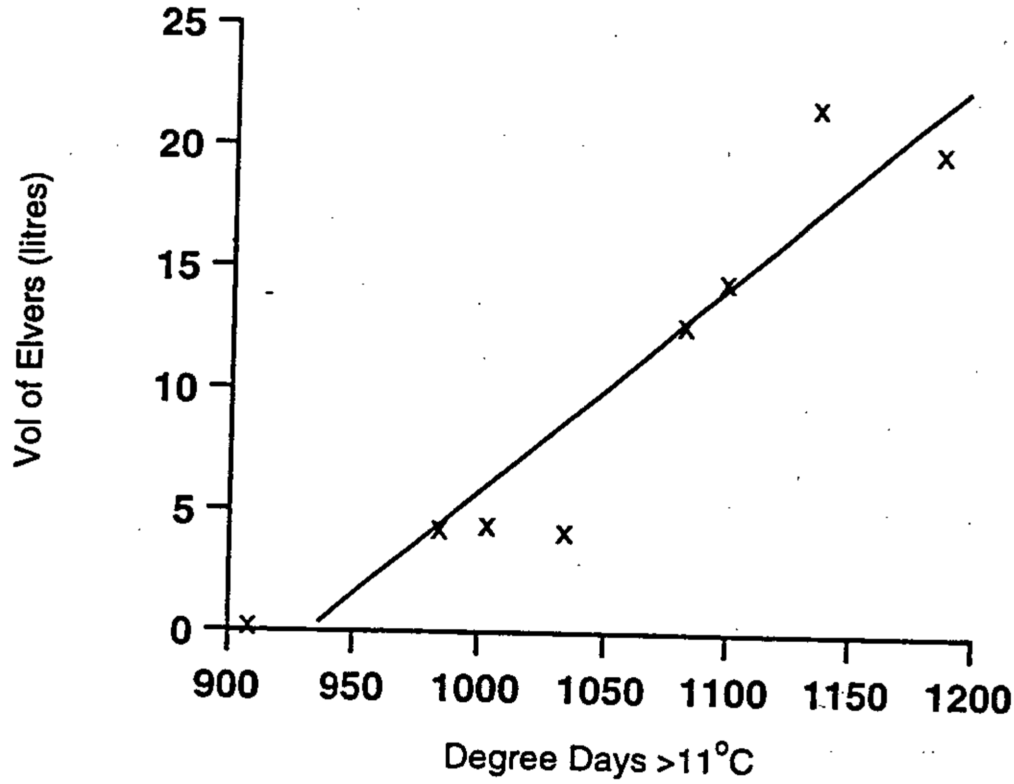

Fig.1. Relationship between water temperature (degree days>11°C) and the catch of A.anguilla elvers ascending the River Imsa, Norway (re-drawn from Hvidsten 1985a)

Tongiorgi *et al.* (1986) concluded that under very low temperature conditions (<6°C), such as those that occur in northern seas in the winter, glass eels are strongly attracted to flowing fresh water at equal or higher temperatures. In contrast, at higher marine temperatures such as those in winter in temperate seas, glass eels migrate towards colder water. This preference for colder water induces the glass eels first to approach the coast, where winter temperatures are colder than the open sea, and then to approach inland fresh waters.

These conclusions concur with those of Hiyama (1952), who concluded that at sea water temperatures ca. 11°C, the elvers prefer colder river waters, but they do not support Hiyama's claim that the preference is inverted at temperatures above 14°C.

Although temperature is clearly important it is not the sole orientating factor because upstream migration also takes place when freshwater temperatures approach those of sea water. Other factors, such as tidal cycles, rheotaxis, olfactory stimuli (Pesaro *et al.*, 1981), may singly or together control migration. For example, these authors observed that migration was stimulated by water that had contained older eels, but not by water that had contained other elvers. They suggested that survival in this crucial phase of the eel life-cycle is probably ensured by more than one factor, because the environmental conditions encountered are extremely variable.

3.3 *Water velocity*

River current velocities can have a strong impact on upstream migration of juvenile eels, especially over obstacles, even though eels are adept at utilizing the low velocities associated with rough bottom substrata. However, there are some variations in the preferred and maximum velocities recorded, probably because of the difficulties in measuring the precise water velocity striking the head of the eel (commonly called 'nose velocity').

Sörensen (1950) found that at 20°C, the maximum flow velocity against which 7-10cm *A. anguilla* could make headway along an experimental fish ladder with 1.2 m long sections, was between 60 and 90 cm s^{-1}. There was absolutely no progress at velocities of 150 cm s^{-1}.

Barbin & Krueger (1994) observed that *A. rostrata* elvers in an experimental flume utilized the lower flow velocities associated with the bottom substratum for upstream migration at mid-water velocities of 10-40 cm s^{-1}. However, if the rough substratum was absent, elvers readily swam upstream only at velocities less than 20 cm s^{-1}. Progress over barriers such as rocks and dams was limited by water velocity because 50% of elvers in the non-substratum chamber were unable to maintain position for swimming at velocities over 30 cm s^{-1}. The authors suggested that migrations may be limited by the availability of resting places for the eels.

McCleave (1980) found that swimming endurance time for *A. anguilla* elvers of 72mm mean length decreased logarithmically with increased swimming speed from 3.0 min at 3.5 body lengths s^{-1} to 0.7 min at 5.0 body lengths s^{-1} and then to 0.27 min at 7.5 body lengths s^{-1}. There appeared to be an inflexion at about 5 body lengths s^{-1}, with the relationships calculated from above and below this point being, respectively:

$$\log Y = 1.9404 - 0.4188X \quad (r^2 = 0.54, n = 52)$$

$$\log Y = 0.6356 - 0.1611X \quad (r^2 = 0.23, n = 60)$$

No differences were found between elvers in the sea or in fresh water. In still water, elvers could swim at high speeds for ca. 10 to 45 min before exhaustion, depending on their swimming speed. Elvers would be able to make virtually no progress against water velocities over 50 cm s^{-1}.

McCleave (1980) concluded that drift in coastal waters and selective tidal stream transport (STST), probably involved swimming speeds below those he tested in his study. STST involves the eels migrating vertically into the tidal flow of water and then returning to the bottom at slack water. McCleave suggested that STST is important for elvers because they cannot usually make much progress by swimming against tidal currents. This view is supported by other observations (e.g. Creutzberg, 1961; Westerberg, 1984).

In addition, McCleave (1980) proposed that migration of elvers into freshwater streams involves avoidance of the free stream speeds and a combination of burst and sustained swimming. This variation in swimming performance may be facilitated by an additional growth of white muscle in elvers entering rivers from coastal waters (Romanello *et al.*, 1987). White muscle is designed for burst swimming activity whereas red muscle is utilized for low speed, cruise swimming. Red muscle increases during the metamorphosis from the yellow to the migratory silver eel stage (Pankhurst, 1982).

3.4 *Effects of barriers*

As long ago as 1890, Francis Day noted that '*weirs.... must impede the upward passage of migratory fish*' and that the action of fish passes upon eels requires further study. Subsequent investigations have suggested that even though eels are able to negotiate many weirs and other man-made obstacles, such structures may inhibit upstream migration. For example, in the River Yare, Norfolk, the population density and biomass of eels were higher below five out seven barriers than immediately above them (Bromidge, 1990). Unfortunately, these data are not conclusive and unequivocal evidence on the effect of barriers is rare. This lack of knowledge was identified by the EIFAC *Working Group on Eel*, who proposed several studies (see APPENDIX A, Section 2b).

Despite the lack of quantitative information, the deleterious effect of vertical sluices, dams and barrages on the migration of elvers and juvenile eels is recognized in many European countries, and also for other eel species in other continents (Tesch, 1977; Dahl, 1991; White & Knights, 1994). In Denmark, there is a statutory requirement for owners of structures that could impede migration, to provide passage for elvers and young eels from 15 April to 30 September (Dahl, 1991).

Barriers on the River Thames, together with a commercial eel fishery in the tideway, have contributed to the slow rate of recolonisation above the tidal limit at Teddington since the 1960s, when improvements to the water quality in the tideway commenced (G.Armstrong pers. comm.).

The NRA Severn-Trent Region is implementing a policy of eel pass construction. Although there are apparently no plans to quantitatively assess their effect, trap catches will be used to monitor the number of elvers moving upstream each year.

4. EEL STOCKS

4.1 *Sources of data on eel population densities*

Estimates of eel numbers in the U.K. relate mostly to rivers and drainage channels, although some are from the Norfolk Broads. The majority of estimates were made by the NRA, usually as part of the routine surveys of fish populations carried out in the separate Regions. A few estimates were made by other organisations, mostly for specific research purposes. Some comparative data from rivers in mainland Europe have been extracted from scientific publications.

4.2 *Accuracy of population estimates*

A major problem in assessing the status of eel stocks is the difficulty in obtaining reliable population estimates. Most estimates of eel numbers in U.K. rivers and streams have been based on capture by either netting or electrofishing, depending on the type of habitat. Netting operations were predominately used in deep, slow-flowing channels in the lower reaches of river systems, and most electrofishing is carried out in shallow waters (often wadeable).

In almost all surveys, eels were not the main target species but were by-catches to more important species in the local fishery, either salmonid or coarse. Even when eels were the principal target species, variable capture efficiencies could be encountered because:

a) in electrofishing operations it can be difficult to locate stunned eels on the stream bed or from among aquatic vegetation,

b) in netting operations, eels can readily avoid capture.

Such variability in capture efficiency can have a pronounced effect on the accuracy of subsequent population estimates (see Section 4.4).

4.3 *Capture methods for eel stock assessment*

The principal methods of eel capture in U.K. fresh waters, not including methods used for commercial exploitation, are:

a) electrofishing - by wading or from boats
- using DC, pulsed DC or AC current

b) netting - trawls
- seines, operated in various ways, but normally by draw-down or wrap-around (Coles *et al.*, 1985).

Note that all methods of fish capture have some size-selective bias and those used for eels are no exception (van Willigen, 1987). None of the estimates of population densities detailed in this report have taken into account such selectivity in the estimation process, although Ibbotson *et al.* (1994) excluded eels less than 20cm from their estimates.

Naismith & Knights (1990a) compared the efficiency of eel capture using various sampling techniques: electrofishing, seine nets, trawls and fyke nets. They also compared successive depletion methods and mark-recapture methods of population estimation. No single technique was ideal in all situations because of the inherent difficulty in sampling eels. Moreover, the results of studies carried out over two or three days in open waters could be affected by the mobility of eels, i.e. the impact of high immigration and emigration rates. Mann & Blackburn (1991) encountered this problem when they attempted to lower the population densities of eels in a ca.1km section of a southern chalk stream.

Naismith & Knights (1990a) considered electrofishing or fyke netting methods to be adequate in wide-ranging surveys to record the presence or absence of eels. However, they noted that fyke nets were inadequate for population estimation because of uncertainty in determining the area sampled and because of the mobility of the eels.

Comparison of population estimates derived from netting techniques (draw-down or wrap-around) or electrofishing (mostly pulsed DC) in coastal drains in the NRA Anglian Region (Lincolnshire) showed that, although the mean sizes of eels caught were approximately the same, electrofishing produced much higher estimates of population density (Figure 2). This occurred, despite the results of an electrofishing study by Ibbotson *et al.* (1994) in a small lowland stream, which demonstrated that eel densities were much higher in slower-flowing, deeper sections than in adjacent, shallower sections.

Similar results have been recorded in surveys of whole river catchments; most estimates by netting in the deeper, downstream sections are lower than those by electrofishing in upper sections of the river. This is despite the strong likelihood (e.g. Aprahamian, 1986) that population densities in downstream sections and in estuaries are higher than those in upstream sections. An example of this is seen in the River Dart catches (Figure 3).

Extremely low population densities were also obtained by seines and trawls in the Norfolk Broads. As these waters support valuable commercial eel fisheries, these low values are clearly gross underestimates. Thus, although estimates from net captures are presented in this report, they are of very little use because of the uncertainty over their accuracy. Even the absence of eels from a netting operation does not necessarily signify that they are absent from the area of water sampled.

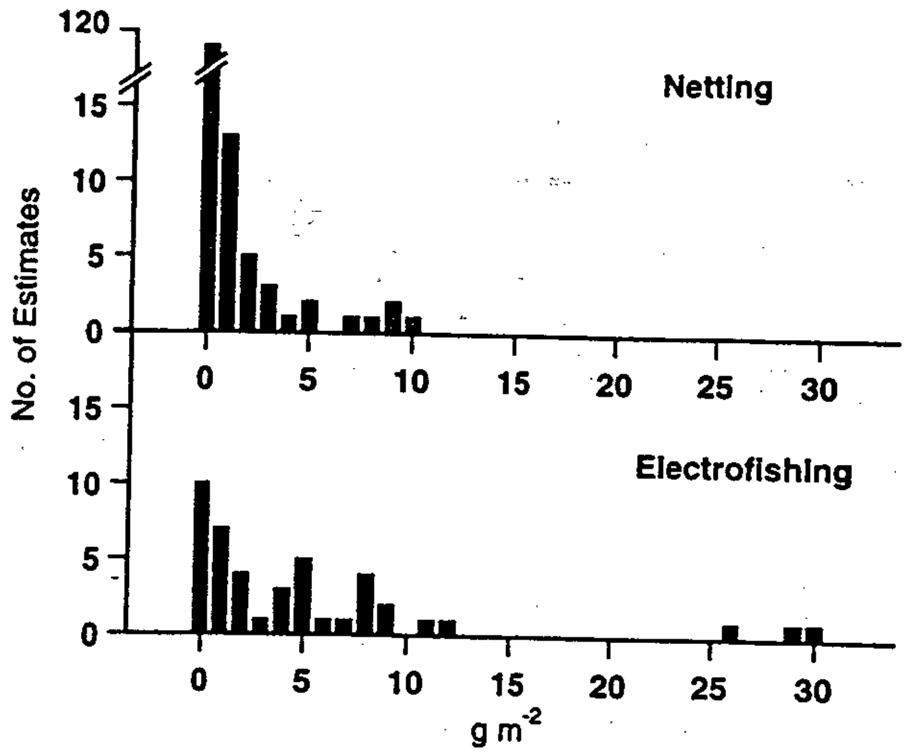

Fig.2. Frequency distributions of biomass estimates (g m^{-2}) of A. anguilla in the River Ancholme and Lincolnshire coastal drains, based on capture by netting and electro-fishing. Data derived from fish survey reports by the NRA Anglian Region.

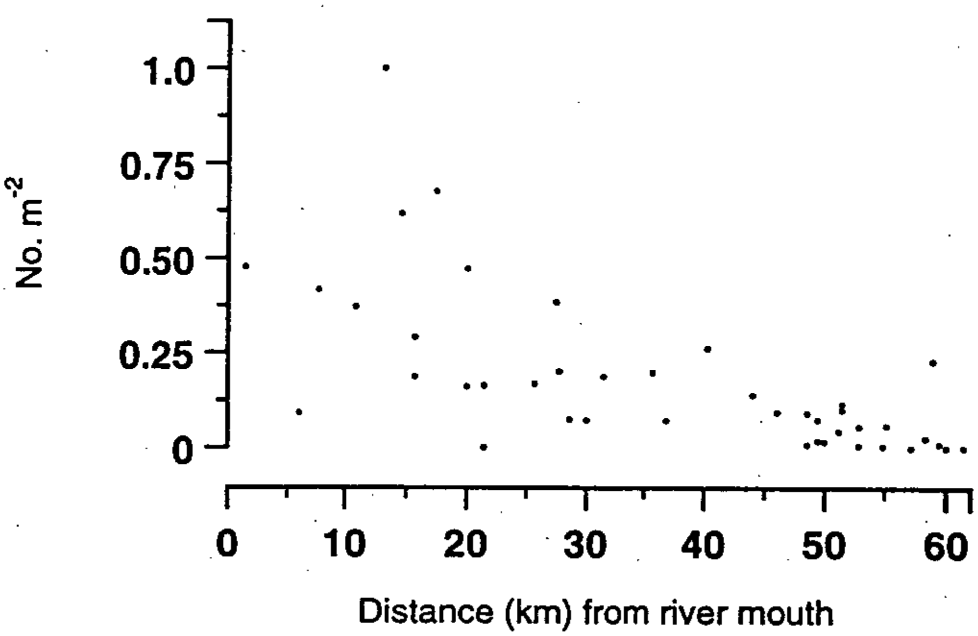

Fig.3. Population estimates (No. m^{-2}) of A. anguilla in the River Dart, Devon, in relation to distance from the river mouth. Data from a 1987 fish survey by the NRA South West Region.

4.4 *Use of catch data to estimate population densities*

Some of the capture methods described in Section 4.3 were used in NRA surveys as a basis for catch depletion estimation although, on occasion, single catches have been used to indicate minimum densities. Mark-recapture methods have been used rarely in the U.K. to estimate the population densities of eels.

Catch depletion methods require that a constant fraction of the fish present in a chosen study area is caught in each fishing session (i.e. fishing efficiency remains constant) and that the fraction caught should be reasonably large (usually not less than 30%). Where these criteria are not met, the numbers of eels actually caught in the successive catches can be used as a MINIMUM estimate.

A handicap in assessing eel information in NRA survey reports is that there are few data on the numbers of eels caught in separate fishings; in most cases only the calculated population estimates are given. Thus, there is no way to check whether the underlying assumptions of the methods used were met.

Naismith & Knights (1990a) observed that, on occasion, more eels were caught in the second catch than in the first. This phenomenon was found also in a 4-catch depletion exercise in a small stream in southern England (Mann, unpublished data). Catches were made over two days within a section of stream confined by fine-mesh barriers (Table 4).

TABLE 4. Successive catches of eels in a screened section of a southern chalk stream in March 1964. Capture efficiencies (p) are based on a population estimate of 928 (see text).

		Catch	No. caught	p
Day 1	a.m.	1	152	0.167
	p.m.	2	202	0.267
Day 2	a.m.	3	93	0.167
	p.m.	4	126	0.292

One possible explanation of this pattern of catches is that the first fishing drew many eels from the reed beds but not sufficiently quickly for the fishing team to see and catch them. In the afternoon the eels had not returned to the reeds and were therefore more vulnerable to capture. Overnight they returned to their original habitat and the following day the sequence was repeated. In this instance the combined catch from the two fishings on each day was counted as a single catch and a 2-catch depletion estimate of 928 (SE ± 99) eels is based on this premise, using either Zippin (1958) or Seber & Le Cren (1967) methods of estimation.

In a study at the same and adjacent sites, Ibbotson *et al.* (1994) demonstrated that eel density is positively correlated with the amount of instream cover and negatively correlated with current velocity and substratum particle size.

4.5 *Stock densities*

Summaries of eel population densities from NRA surveys are set out in Appendix A. The NRA Survey Reports usually contained estimates of population densities as Numbers m^{-2}, or $100m^{-2}$, but some also included biomass data (g m^{-2} or g $100m^{-2}$). A few Reports gave only presence/absence information. The numbers of sites with different population densities of eels in four NRA Regions is shown in Table 5. In the four Regions, most estimates are less than 5 eels $100m^{-2}$ (0.05 m^{-2}), although the NRA Southwestern Region had generally higher estimates than elsewhere.

Data for the Thames Region are not included, but details of a comprehensive survey will be available soon. In general the proportion of sites containing eels decreases with increasing distance upstream from Teddington Weir (the tidal limit). No eels occur in the upper reaches of the majority of tributaries, nor in the principal tributaries above the River Colne confluence, except where stocking has taken place. Even where eels do occur in other areas, their densities are very low and are often fewer than 0.0001 $100m^{-2}$ (data from G.Armstrong, Thames NRA).

Data from scientific publications for U.K. and non U.K. eel populations are summarised in Tables 6 and 7.

TABLE 5. Frequency distribution (Number of individual site estimates) of population densities (Number $100m^{-2}$) of eels in five NRA Regions, mostly based on data from unpublished NRA/WA reports. The Anglian data are for Norfolk, Suffolk and Essex only.

N $100m^{-2}$	0 - 0.9	1 - 4.9	5 - 9.9	10 - 49.9	50 - 99.9	100+	Total	Median density
NWest	89	163	35	22	1	1	311	1.94
South	6	16	5	8	2	0	37	3.80
SWest	118	169	85	144	12	7	535	4.30
Anglian	67	74	39	27	0	1	208	2.40
S-Trent	243	89	22	16	0	1	371	0.44

TABLE 6. Population densities and biomasses of eels in U.K. rivers and streams recorded in scientific publications.

River	No. of sites	N $100m^{-2}$ Min.- Max.	g $100m^{-2}$ Min.- Max.	Reference
Brett & Chelmer	4	0.005- 0.05	3.5 - 21.0	Barak & Mason (1992)
Severn & tribs.	11	0.12 -12.17		Aprahamian (1986)
Severn & tribs.	10	0.05 - 3.17		Aprahamian (1986)
Tweed		0.13 - 0.93	3.6 - 32.8	Hussein (1981)
Thames 1981-88		0.0 - 0.06	0.0 - 7.0	Naismith & Knights (1993)
Tadnoll	15	0.5	1.0	Mann & Blackburn (1991)
Frome (Dorset)	5	0.05 - 2.00		Ibbotson *et al.* (1994)
181 U.K. streams	181	0.03 - 0.10	1.0 - 37.4	Turnpenny (1989)

TABLE 7. Population densities and biomasses (means or minimum-maximum) of eels in non U.K. waters recorded in scientific publications.

River Country	N m^{-2}	g m^{-2}	Reference
Oued Sebaou Algeria	0.015	0.304	Penczak & Molinski (1984)
Bransdrup Denmark		7.5	Tesch (1977)
Pool Seeland		1.9	Tesch (1977)
Naera Stand Denmark		15.0	Tesch (1977)
Danish streams	1.01 - 6.0		Rasmussen (1977, 1983)
Koge-Lellinge Denmark	0.595 -1.01	16.32	Rasmussen & Thirkildsen (1979)
Granslev Denmark	0.05	1.0	Mortensen (1982)
Breagagh Eire	0.052	5.2	Moriarty & Nixon (1990)
R. Dunkellin Ireland	0.03 - 1.34		Callaghan & McCarthy (1991)
Nivelle France		10.83	Neveu (1981)
Pyrenean streams		10.84	Neveu (1981)
Chabatches Spain	0.303-0.375		Lobon-Cervia *et al.* (199)
Pilica Poland		0.046	Mann & Penczak (1994)
Imsa Norway	0.0116	1.02	Vollestad & Jonsson (1988)
12 streams Sweden	0.017-0.063		Degerman *et al.* (1986)

4.6 *Mean weights*

The data from the NRA Survey Reports show that, in large catchments, there is a progressive increase in the mean weight of eels from the estuary to the upper reaches. However, this phenomenon was not apparent in short rivers. Where an upstream increase occurred, this was usually accompanied by a decrease in population density, e.g. in the River Dart (Figure 3). A similar result has been also observed in the Thames catchment by Naismith & Knights (1993).

The mean weights of yellow eels in Lincolnshire caught in electrofishing or netting surveys rarely exceed 150g (ca. 45cm), and most values are about 50g (ca. 32cm). The limited data from other U.K. waters indicate a similar range of values. According to Morrice (1989), most full-time eel fishermen regulate their own fishery by taking only eels larger than 115g (excluding elver catches). In Northern Ireland, a minimum size limit of 30cm has been operated since 1982 (Morrice, 1989).

4.7 *Mortality rates*

Estimation of eel mortality rates ideally requires accurate information on age structure and population densities in successive years. The instantaneous mortality rate (Z) is then calculated as:

$$Z = (\ln Nt_1 - \ln Nt_2)/(t_2 - t_1)$$

where Nt_1 is the number of eels of a particular age group at time t_1, and Nt_2 is the number at time t_2 (usually one year later). Table 8 shows the few estimates of instantaneous mortality rate that have been published, none of them from U.K. populations.

TABLE 8. Estimates of the instantaneous mortality rates of *A. anguilla* in different waters.

Location	Mortality rate (per day)	Reference
R.Imsa Norway	0.0002-0.0006	Vollestad & Jonsson (1988)
Koge-Lellinge å Denmark	0.0015	Rasmussen & Thirkildsen (1979)
Danish streams	0.0008	Berg (1990)
Danish streams	0.0107-0.0233	Berg & Jorgensen (1994)

4.8 *Production and yield*

A useful synthesis of population biomass, recruitment and the rates of growth and mortality is PRODUCTION. This has been defined (Ivlev, 1966) as:

'*the total quantity of tissue elaborated by a fish population during a stated period of time, even though not all of it may survive to the end of that time.*'

This is different from YIELD which, in fishery terms, is that part of the fish production that is cropped by man. Thus, yield is dependent upon the level of production and on the fishing effort.

The relatively few data on these two parameters are summarised in Tables 9 to 13.

TABLE 9.Estimates of annual production (g m^{-2} $year^{-1}$) of *A. anguilla*. Parentheses = minimum and maximum values.

River/stream	Production	Reference
A. ENGLAND		
Severn	(0.0 -6.52)	Aprahamian (1986)
Tadnoll	3.42 (3.13-3.75)	Mann & Blackburn (1991)
B. DENMARK		
Koge-Lellinge å	9.3	Rasmussen & Thirkildsen (1979)
Granslev å	0.5	Mortensen (1982)
C. POLAND		
Pilica	0.04	Mann & Penczak (1984)
Pilawa & Dobrzyca	(0.02-0.56)	Penczak *et al.* (1986)
D. ALGERIA		
Oued Sebaou	(0.04-0.49)	Penczak & Molinski (1984)
E. ITALY		
Po Delta	3.6	Rossi (1979)

TABLE 10. The commercial yields (kg ha^{-1}) of *A. anguilla* in lakes and reservoirs; parentheses indicate minimum andmaximum values.

Lake	Yield	Reference
L. Neagh }	16.1 (yellow)	Moriarty (1990)
}	5.5 (silver)	
R.Shannon } Ireland	0.7 (yellow)	
}	1.1 (silver)	
L.Corrib }	0.9 (yellow)	
	0.1 (silver)	
Small lakes Bergen	3.2	Jensen (1961)
5 lakes near Molde	0.17-0.11	Hvidsten (1985b)
L. Pyhäjärvai SW Finland (1976)	0.09 (= 0.26% of total fish yield)	Sarvala *et al.* (1994)
L. Neagh	20.0	Tesch (1997)
Schleswig-Holstein:	13.0 (8.8-20.8)	
various lakes	12.0 (7.5-15.6)	
	7.9 (4.9-13.5)	
	6.0 (3.0- 9.4)	
	5.0 (3.5- 7.7)	
	4.2 (2.2- 6.2)	
L. Rögglin	7.9 (2.0-15.1)	
L. Steinhude	4.5	
Schwerin waters	3.2 (1.9- 4.5)	
L. Dümmer	2.8	
L. Storkow	2.45 (0.3- 6.1)	
L. Bederkesa	2.0	
Eder reservoir:		
1937-58	0.33 (0.03-0.9)	
1959-65	2.8 (2.2- 4.1)	
L. Sakrow	1.8 (0.6- 3.7)	
W. Berlin waters	1.8 (1.5- 2.0)	
Oder reservoir	0.3	

TABLE 11. The commercial yields (kg ha^{-1}) of *A. anguilla* in coastal waters.

Location	Yield	Reference
Valli Lagoon	30 - 40	Tesch (1977)
L. Convent	35.6	
Ijsselmeer	ca. 10.0	
Strelasund	7.0	
Estuaries, U.K.	0.45kg net^{-1} day^{-1}	Harrison (1986)

TABLE 12. The commercial yields (kg ha^{-1}) of *A. anguilla* in rivers, streams and drainage channels.

River	Yield kg ha^{-1}	Mean weight (g)	Reference
Burrishoole			Poole *et al.*
1959-63	0.33-0.44	75- 88	(1990)
1970-79	0.31-1.55	88-139	
1980-88	0.33-1.45	131-206	
Mean	1.1		
R. Werra	46		Tesch (1977)
R. Oder	44 (32-60)		
Beste, Barnitz	23 (11-38)		
Trave, upper	20 (11-35)		
lower	16 (8-25)		
Weser, upper	12.2		
lower	7.3		
Elbe, upper			
1896-1928	11 (2-35)		
1927-1937	7		
lower	25-50		
Rhine	3.5		
Lahn (Rhine)	9.0		
Fulda (Rhine)	8.0		
Mosel (Rhine)	7.0		
Diemel (Weser)	8.0		
Ems	2.8		
Imsa, 1975-81	1.9	450	Hvidsten (1985b)
Inland Waters UK	0.37-0.57 kg net^{-1}day^{-1}		Harrison (1986)
N. Lincs.	112 (0-450)		

Many of the data on commercial yields were summarized by Tesch (1977) and are shown in Table 13.

TABLE 13. Summary of yield data (kg ha^{-1} $year^{-1}$) of *A. anguilla* from lakes and rivers, derived from Tesch (1977).

	High	Average	Low
Lakes	10-40	3-10	<3
Rivers	20-50	5-20	<5

5. AGE & GROWTH

5.1 *Accuracy of age determinations*

The ageing of fish is an important prerequisite to stock assessment. A large number of techniques have been used for ageing eels, nearly all using the sagittal otoliths. Scales were discarded as unsuitable some years ago, a decision confirmed more recently using tetracycline labelling (Dekker, 1986). By convention, ages are recorded only for the period after the eels have entered fresh water or coastal waters (i.e. the time taken for leptocephali to cross the Atlantic Ocean is not included).

The sagittal otolith ('ear bone'), is located near to the optic lobes of the brain. There are four principal methods of preparing the otoliths in order to see the annual rings (annuli):

a) Otoliths are ground down so that the annuli are more visible, or sections are taken through the centre of the otolith,
b) Otoliths are scorched in a flame and then cracked through the centre,
c) Otoliths are examined whole in a clearing agent such as cedar wood oil,
d) A variety of advanced techniques (e.g. image analysis) are used to identify the annuli.

Although various rings can be seen readily on eel otoliths, care is needed in their interpretation. Supernumerary zones are frequently formed during the growing season, which may correlate with periods of low feeding intensity or starvation (Liew, 1974), and these can be easily confused with true annuli. Moriarty & Steinmetz (1979) distributed four samples of eel otoliths to five research workers, each of whom used a different reading method. There were considerable differences in the ageing results, frequently in the range of 3 to 10 years.

Moreover, few attempts have been made at validating the age determination methods described above, although some studies have described the use of otoliths from eels of (partly) known age (Moriarty & Steinmetz, 1979; Berg, 1985). Note that it is important to distinguish between accuracy and precision; the latter relates to the reproducibility of results, which does not necessarily signify accuracy or validity.

The EIFAC *Working Group on Eel* have recommended the use of the burning and cracking technique (Christensen, 1964; Moriarty, 1973, 1983), but others have reported situations in which the examination of ground otoliths on a black background using reflected light (Mann & Blackburn, 1991) or of otoliths cleared in ethanol (Vollestad, 1985) gave results comparable with the burning method. Within the U.K., the N.R.A. Fish Ageing Service at Brampton, Cambridgeshire, follows the burning and cracking method except for young eels (under ca. 6 years old) for which ground otoliths are used.

Recently, Lecomte-Finiger (1992) has described daily growth rings in the otoliths of elvers, which may point to another comparative method for the future. Using this method, he claimed that leptocephali crossed the Atlantic Ocean in less than one year, not over ca. 2 years as previously thought. However, as with the other methods, verification of the nature of the 'daily' rings is needed before such a claim can be substantiated.

Thus, the results of eel ageing remain equivocal, and this must be borne in mind when examining the information on aspects of age and growth in the following sections. This is particularly true with respect to the age and growth data that were collected before the importance of some of these problems was recognised.

5.2 *Growth rates*

The von Bertalanffy growth equation is frequently used to describe the growth of fish species, but eel growth curves do not always fit the model. Often a graph of length on age gives a straight line, not the asymptotic curve implicit in the von Bertalanffy model.

The von Bertalanffy equation is:

$$L_t = L_\infty(1 - \exp(K(t - t_o)))$$

where L_∞ is the asymptotic length, L_t is the length at age t years, t_o is the hypothetical age when length is zero, and K is a growth coefficient. Values of the von Bertalanffy coefficients for some selected populations are shown in Table 14.

TABLE 14. Coefficients of the von Bertalanffy growth equation for some *A. anguilla* populations.

Location	L_∞ (mm)	K	Max age (years)	Reference
Helgoland	832	0.076	8	Rossi & Colombo (1976)
Commacio	736	0.129	11	" "
Valle Nuova	872	0.187	10	" "
R. Barrow	1045	0.046	14	Moriarty (1983)
R. Barrow	805	0.064	6	" "

The coefficients for the River Barrow (Table 14) indicate that the mean increment of eels was 33mm $year^{-1}$, which agrees well with information from tagged eels that were recaptured after four years.

Rossi & Villani (1980) recorded that male eels in warm lagoons in Italy became silver after 2-3 years and females after 3-4 years. These data compare with 9 years for males in Holland (Deelder, 1957) and 7.3 years in Northern Ireland (Frost, 1950); 11 years for female silver eels in Denmark (Rasmussen, 1983) and 12 years in England (Frost, 1945).

Fernandez-Delgado *et al.*(1989) showed that eels in brackish water grow faster than those in fresh waters, but that latitude also had an effect (higher growth rates at lower latitudes). As the migratory phase is more dependent upon length than upon age (Tesch, 1977), this means that eels in brackish waters become migratory at an earlier age. Also, the number of age-groups is lower in fast-growth populations (southern, brackish waters) than in low-growth populations (northern, fresh waters).

Data from the River Thames (Naismith & Knights, 1993) provide a good example of the levels of growth rates that have been observed within a single catchment (Table 15).

TABLE 15. Growth increments (cm $year^{-1}$) of eels in different parts of the River Thames catchment.

Location	Increment (cm $year^{-1}$)
Enclosed freshwater sites	6.19 - 6.62
R. Darent: eels <25cm	3.38
eels >25cm	5.09
Upper Thames: mostly eels aged 15-27 years	3.80
R. Loddon: eels aged 6 years	5.24
eels aged 10 years	5.87
Thames estuary	4.67 - 6.07

5.3 *Length:weight relationships and condition*

There were no large variations in the coefficients obtained from a least squares regression analysis of Log Weight (g) on Log Length (cm) for eels within the U.K. or mainland Europe (Tables 15 & 16).

TABLE 16. Coefficients from the least squares linear regression: $\log_{10}$Weight (g) = $\log_{10}a + b\log_{10}$Length(cm) for eel populations in U.K. rivers. M= male, F = female, u = sex undifferentiated, N = number of eels.

River	Sex	$\log_{10}a$	b	R^2	N	Ref.
Frome	M/F	-3.126	3.302	0.994	380	1
Bere Stream	M/F	-3.252	3.291	0.988	75	1
Stour	M/F	-3.188	3.188	0.993	548	1
Tadnoll	M/F	-3.251	3.313	0.990	957	2
Medina	M/F	-3.03	3.19	0.975		3
East Yar	M/F	-2.97	3.15	0.975		3
Axe	M/F	-3.066	3.166			4
Yare	F	-3.398	3.353		99	5
Hayle	M/F	-2.824	2.967			6
Weaver	M/F	-2.800	3.041	0.933	31	7
Brett	M/F	-3.174	3.256	0.98	441	8
Chelmer	M/F	-3.161	3.283	0.96	443	8
Teign	M/F	-3.066	3.166		37	9
Hull	M/F	-2.971	3.148	0.983		10
Fraw	M/u	-3.376	3.376			11
Rhyd-hir	M/u	-2.975	3.192			11
Glaslyn	M/u	-3.146	3.298			11
Fraw	F	-2.860	3.105			11
Rhyd-hir	F	-2.734	2.992			11
Galslyn	F	-2.721	3.024			11
Idle	M/u	-3.047	3.200			12
	F	-3.084	3.221			12
Torne	M/u	-3.026	3.191			12
	F	-2.983	3.334			12

References: 1 = Mann unpublished data, 2 = Mann & Blackburn 1991, 3 = IFE Report to NRA, 4 = South West Water Authority, 1979, 5 = Bromidge 1990, 6 = South West Water Authority 1977, 7 = M. Aprahamian, Northwest NRA, pers. comm., 8 = Barak & Mason 1992, 9 = South West Water Authority 1979, 10 = Yorkshire Water 1989, 11 = Sinha & Jones 1967, 12 = Carpenter, 1983.

TABLE 17. Coefficients from the least squares linear regression: log_{10}Weight(g) = log_{10}a + log_{10}Length(cm), for eel populations in mainland Europe. M= Male, F = Female, u = undifferentiated, N = number of fish.

Location	Sex	$log_{10}a$	b	R^2	N	Ref.
R. Imsa	M/F	-2.898	3.073	0.949	1283	1
silver	M	-3.212	3.264	0.833		1
silver	F	-2.854	3.048	0.930		1
Lesina & Varano lagoons	M/F	-3.146	3.206		41	2
Lesina						
silver	M	-2.606	2.912		289	2
silver	F	-2.927	3.115		62	2
Guadalquivir	u	-3.172	3.255	0.972	417	3
	M	-3.008	3.187	0.922	117	3
	F	-3.224	3.279	0.980	94	3
Koge-Lellinge	M/F	-2.799	3.017		358	4
Vester Vedsted	M/F	-3.144	3.23			5

References: 1 = Vollestad & Jonsson 1986, 1988, 2 = Rossi & Villani 1980, 3 = Fernandez - Delgado *et al.* 1989, 4 = Rasmussen & Thirkildsen 1979, 5 = Rasmussen 1983.

5.4 *Sex Ratios*

Differences in the proportions of male and female eels have been recorded in estuaries, and upper and lower sections of the fresh water catchment. In the Thames, males dominate freshwater sites in the lower catchment (there are few eels in the upper catchment), whereas females dominate the saline zone (Naismith & Knights, 1990). A similar situation occurs in the Severn system but, in addition, female eels are also prevalent in the upper catchment (Aprahamian, 1988).

In upper catchments, eel densities are lower than further downstream (see Figure 3), and Parsons *et al.* (1977) found that the frequency of male eels increased with increasing density. However, it is not known if sex is determined at fertilization, or if it is determined phenotypically through environmental influences.

Whatever the cause, the high incidence of large female eels from the upper parts of river systems has important management consequences. For example, the weirs and other barriers that can inhibit the upstream migration of elvers may result in a pronounced decrease in the numbers of large female silver eels that return to the Sargasso Sea to spawn. This potential problem is a major reason why elver migration should be enhanced by the provision of passes over obstacles.

Increasing eel densities in upper catchments by stocking needs to be done with care; overstocking could result in more male eels being produced. For example, Parsons *et al.* (1977) observed an increase in percentage males from 9.3 to 86.0 of silver eels caught in Lough Neagh, Northern Ireland, during the period 1965-1970. Also, they noted that each period of elver transport and stocking in the lough has been followed by a marked increase in the proportion of males among the migrating silver eels.

5.5 *Age (size) of migrating silver eels*

It is generally recognised that yellow (brown) male eels metamorphose to the silver migratory form at a smaller size and younger age than females. In a review of information from many European and North African locations, Vollestad (1992) calculated mean lengths (mm) and ages (years) as 406 and 6.0, respectively, for males and 623 and 8.7, respectively, for females. He also noted a strong correlation between the age at metamorphosis and growth rate ($r^2 = 0.94$ for both sexes), i.e. faster growth rates were associated with younger ages at migration.

The review also described a large geographic variation in mean age and length at metamorphosis of both sexes, with growth rate varying strongly with both latitude and longitude. There was also a correlation between mean length at metamorphosis from the yellow to the silver stage and latitude plus longitude.

Within any one catchment there is a wide spread of ages at which individuals of each sex become silver. For example, the ages of silver eels in the Tadnoll Brook, Dorset were from 6 to 16 years (size range c. 300-450mm) (Mann & Blackburn, 1991). Hence, there was a concomitant wide range in the growth rates of individual eels. Similar results are reported for other populations. This means that difficulties can arise when comparing the growth rates of eels from different rivers or countries.

5.6 *Stimuli for migration of silver eels*

Vollestad *et al.* (1986) suggested that temperatures above 1°C and below 4°C inhibited silver eel migration. They concluded that day length and water temperature were the prime motivational factors but that, once migration had started, migration speed was strongly influenced by water discharge. In addition, Haraldstad *et al.* (1985) noted that migration speed of silver eels was independent of fish length.

In the Ims-Lutsi watercourse, Norway, the seaward migration of silver eels occurred mostly at nights during the autumn at decreasing water temperature. The maximum migration rate was in mid-October at medium and decreasing water discharge (Haraldstad *et al.*,1985). Most eels descended during the first quarter of the lunar cycle, few descended at full moon. It seems likely that migration activity is adapted to periods of low light intensity rather than to lunar phases *per se.*

From 1975 to 1982, water temperature during the migration period ranged between 11 and 17°C. From these data, Haraldstad *et al.* (1985) concluded that there is no particular temperature that triggers the activity. This conclusion compares markedly with test of Vollestad *et al.* (1986), who found that eels in the R. Imsa, Norway, migrated downstream mostly at temperatures 9-11°C, with fewer at higher and lower temperatures. Most (90%) of the variation was due to water discharge and temperature.

Most males and smaller females migrated earlier than larger females, possibly because the larger (mostly older) females came from upstream sites in the river.

Vollestad *et al.* (1994), using transplanted, tagged silver eels, found that 74% of the migratory speed (variation in time from release to subsequent recapture in a trap at the river outlet) was accounted for (in order of decreasing importance) by variation in date of release (because of the associated variation in day length), water discharge at time of release, moon phase at date of release. Water temperature at the date of release did not explain any of the remaining variatio, although it accounted for 33% of the variation in recapture rate (i.e. the numbers of migrating silvers were determined by water temperature).

The enhanced migration at higher discharges has the advantage that energy requirements are less and that downstream displacement is more rapid (Jonsson, 1991). Also, predation on the eels is more difficult under such conditions. From tagging experiments (Vollestad *et al.*, 1994) concluded that, when river conditions were not suitable, silver eels probably delayed migration until the following year.

6. MANAGEMENT OF EEL STOCKS

6.1 *Effects of elver stocking*

Berg & Jorgensen (1994) consider that the widespread fall in the numbers of ascending elvers has made rehabilitation of eel fisheries through fish passage construction and habitat improvement of streams of little relevance. However, they appear to have little support for this opinion and, in Denmark, there has been a long tradition of stocking elvers or small eels (1 to 20g) in lakes, usually by local commercial fishermen (Berg & Jorgensen, 1994).

Per unit area, rivers have generally higher production capacity for eels than lakes. Hence, since 1987, the Danish Government has funded large scale stocking in waters, especially rivers and streams, where the public has exclusive access to the fishery.

In Lough Neagh, Northern Ireland, most of the elvers migrating up the River Bann are caught and transported to the lough (Moriarty, 1990b; Winfield *et al.*, 1993). The average rate of stocking is 446 elvers ha^{-1}, which has resulted in yields of 16.1 kg ha^{-1} of yellow eels and 5.5 kg ha^{-1} of silver eels. However, there has been a general decrease in the numbers of River Bann elvers stocked (Table 17) and these have been supplemented with elvers from other catchments. In the River Shannon, elvers are stocked at 357 ha^{-1}, giving a yield of 0.7 kg ha^{-1} (yellow eels) and 1.1 kg ha^{-1} of silver eels (Moriarty, 1990b).

TABLE 18. Numbers of *A. anguilla* elvers stocked per hectare in Lough Neagh.

Years	No. ha^{-1}	S.E.
1933-1947	520.2	34.5
1960-1979	342.1	32.8
1980-1992	243.2	45.1

TABLE 19. Stocking rate and yield of *A. anguilla* in Lough Neagh (39626 ha); parentheses = numbers of elvers stocked from other sources.

Year	No. elvers x 10^6	Yellow eel catch (t)	Silver eel catch (t)
1965	11.4	236	329
1966	18.5	284	332
1967	5.7	327	242
1968	7.6	382	204
1969	12.3	368	238
1970	12.0	515	237
1971	12.5	610	233
1972	8.7	580	125
1973	7.6	561	162
1974	17.6	587	179
1975	13.9	575	187
1976	8.8	481	145
1977	19.3	454	236
1978	15.1	544	280
1979	6.3	701	341
1980	7.5	668	245
1981	9.1	680	228
1982	11.6	704	210
1983	0.7	661	203
1984	4.6 (4.0)	806	166
1985	1.7 (10.9)	615	135
1986	5.5 (17.8)	521	130
1987	5.0 (13.8)	503	121
1988	7.9 (6.3)	502	151
1989	4.7	642	152
1990	6.9	612	123
1991	2.0	578	121
1992	2.9 (2.4)	532	148

The most extensive elver stocking in England is carried out by the NRA Severn-Trent Region. Since 1973, elvers have been collected in April/May as they enter the River Severn and then reared under elevated temperatures in a double-skinned greenhouse at Gloucester (Bristol Channel Fisheries). On average, 15-20 x 10^3 eels, mean weight 1.5-2.0g, are stocked from a boat along the Warwickshire Avon during October and November.

Scatter stocking in the Avon is preferred to releasing all the elvers in one place. This practice is supported by the findings of Berg & Jorgensen (1994) who carried out stocking experiments with 0.3 to 1.1g eels. They found that, after spot stocking, densities were in the range of natural densities and independent of the number stocked. Hence, the post-stocking density represented the carrying capacity of the stream in question. Scatter stocking reduced the level of density-dependent mortality and a positive correlation was observed between stocking density and recovery density ($r^2 = 0.75$).

Occasional stocking has occurred in the upper catchment of the River Thames, both in the past (Naismith & Knights, 1993) and in 1994 (G.Armstrong, pers. comm), but there is no regular programme of enhancement.

Tesch (1977) lists several lakes where stocking has been beneficial, including L. Vilm (E. Pomerania), which was first stocked in 1909 and where, over next 30 years, the yield rose from 0.7 to 8.0 kg ha^{-1} $year^{-1}$. In Polish lakes, an average yield of 3.99 kg ha^{-1} $year^{-1}$ is achieved from a stocking rate up to 96.4 elvers ha^{-1} (Leopold, 1985).

Tesch (1977) also noted that an appreciable increase in yield occurs 3 to 4 years after stocking with young eels, but 8 to 10 years after stocking with glass eels. He reported that better results were found in southern waters than in central/northern Europe, presumably because of the more rapid rates of growth in the warmer waters.

6.2 *Effects of passes and traps*

In Section 3.4 reference is made to the absence of quantitative information on the impact of barriers to eel migration. Lack of such information makes assessment of pass construction difficult, although some observational data have been collected.

In the River Nene, a barrier at the tidal limit (Dog in a Doublet sluice) near Peterborough caused large aggregations of eels immediately downstream, where they were vulnerable to the effects of a sewage effluent. Installation of a pass in 1994 appears to have alleviated this problem considerably (C. Reed pers. comm.), but further monitoring is required for the full effect to be understood.

It would be a great advantage if such monitoring was carried out in all situations where ameliorative measures are made, although the lack of data before a trap is operated makes any assessment of the 'before and after' situation difficult.

6.3 *NRA Regions*

Severn-Trent NRA have a policy of installing elver passes on weirs in the Severn catchment, particularly on the Warwickshire Avon. By April 1995, passes will have been built as far upstream as Evesham. Some of the passes are combined with an elver trap in order to monitor elver runs (at a cost of ca. £5K per trap); these are at Abbey Mill (Tewkesbury), Stanchard (Tewkesbury), Strensham, Evesham and one on the main River Severn. The overall aim is to increase the natural migration of young eels upstream and, thereby, decrease the need for elver transport and stocking.

An elver pass was built at the head of tide (Dog in a Doublet sluice) on the River Nene (NRA Anglian Region) in 1994 in conjunction with a coarse fish pass. This was primarily to alleviate a pollution problem immediately downstream of the tidal barrier, which occasionally resulted in large fish kills. However, it will increase the numbers of young eels moving upstream, and it is hoped that other passes will be constructed on barriers upstream as funds become available.

Passes for salmon have been constructed on weirs in the River Thames catchment. These can be utilised by larger eels (ca. 30cm or more) but, under most flow conditions the current velocities are too great for the small eels to swim against. The NRA Thames Region are currently considering a proposal to construct eel passes at weirs on the lower Thames and lower order tributaries. Passes have been already included in projects on the River Wey (Stoke Mill) and River Colne (Staines Lino Mill).

Other NRA Regions have no plans to install eel passes. In many cases this is because barriers on the rivers are not a major handicap for upstream migration. In other areas, for example in some rivers in the Anglian Region, the constraint to such enhancement appears to be largely financial.

7. COMMERCIAL FISHERIES

Previous reports (Morrice, 1989; White & Knights, 1994) have indicated the problem in assessing the level of commercial exploitation of eel stocks in the U.K. It would appear that a similar problem exists in other European countries. The principal difficulty is the reluctance of commercial eel fishing interests to reveal details of their catches. Consequently, this section adds little to what is know already concerning commercial eel fisheries.

A guide to regional differences is shown (Table 19) by the numbers of commercial eel fishing licences issued by the NRA Regions (or their predecessors).

TABLE 20. Numbers of commercial eel fishing licences issued in the 10 NRA Regions from 1983 to 1991 (from MAFF Reports: Salmon and Migratory Trout Fisheries Statistics for England and Wales)

Year 19_	83	84	85	86	87	88	89	90	91
Northum.	156	207	262	146	92	127	70	77	70
Yorks.	324	255	337	223	340	263	224	170	140
Anglian	555	847	1004	726	673	1040	779	835	1104
Thames	358	358	360	444	458	582	215	138	167
South.	-	-	1	30	57	54	53	75	57
Wessex	49	33	29	55	42	53	189	283	238
S.West	-	24	22	42	47	44	23	38	40
S-Trent	1088	851	715	631	887	739	737	767	580
Welsh	508	674	881	583	696	413	374	317	237
N.West	22	28	29	31	38	46	36	58	31

In five Regions there has been a steady decline in the numbers of licences issued (Northumbria, Yorkshire, Thames, Severn-Trent, Welsh), but small increases have occurred in the Southern and Wessex Regions. The numbers issued in other Regions have remained relatively stable, although those in the Anglian Region have fluctuated the most.

TABLE 21. The commercial catches (tonnes) of eels in the 10 NRA Regions as compiled for EIFAC, but which are based on incomplete catch returns.

Year 19_	87	88	89	90	91
North.	--	--	--	--	--
Yorks	--	5.24	1.84	1.12	1.18
Anglian	2.14	10.00	10.00	10.00	10.00
Thames	10.12	5.30	3.69	3.05	3.94
South.	30.10	30.00	30.00	--	--
Wessex	--	213.19	22.68	20.11	10.51
S. West	1.78	5.38	3.53	3.15	3.15
S-Trent	28.00	28.00	28.00	28.00	8.00
Welsh	6.81	5.83	0.78	1.01	1.54
N. West	2.76	--	0.68	3.20	1.07
Total	81.71	301.94	101.20	69.64	39.39

The data in Table 20 gives, at best, a minimum estimate of the commercial eel catch. Catches are likely to be higher than those recorded for EIFAC because of the reluctance of eel fishermen to divulge details of their catches (White & Knights, 1994). No sensible management decisions can be made from reliance on these data sets.

8. RECOMMENDATIONS FOR FUTURE STUDIES

8.1 *Gaps in current knowledge*

With the exception of studies of the Thames and Severn catchments, little is known about U.K. eel stocks. The following areas of knowledge are regarded as requiring attention:

a) Accurate population estimates.

b) Size, age and sex structure, especially of the commercial catches.

c) Age and size of male and silver eels.

d) Timing of elver runs and numbers/sizes migrating.

e) Estimation of silver eel escapement.

f) Sea age of elvers as they reach the U.K. coast.

To assist in this work, the application of a standard age determination method for eels is required. To make the results from U.K. rivers comparable with studies in other countries, it is recommended that the burning and cracking method is used, as advocated by the EIFAC *Working Party on Eel* and currently followed by the NRA Fish Ageing Service (NRA Anglian Region).

8.2 *Research priorities*

Some of the recommendations listed in this section will be extremely difficult to realise and, hence, the priority list (below) indicates the most tractable projects first. However, it is worth noting that most of the projects are interrelated and lack of knowledge on one topic may decrease the value of information on other topics.

A powerful tool to assist in management decisions is the use of modelling techniques. An example of the potential value of this approach is the construction of a compartmental mortality model for eels in the Thames estuary (Naismith & Knights, 1990b). The authors concluded that, despite the poor recruitment of elvers, the stock was not being overexploited. Further development of this model for use in other situations would be extremely valuable but, as with all models, its value will depend greatly on the accuracy of the input data.

Priority list:

a) Review of age determination methods. Production of short report giving practical details of recommended (standard) procedure (for NRA biologists and others).

b) Monitoring of elver runs and establishment of elver passes on key rivers in all or most NRA Regions.
Data: Numbers per month, per year; size & age structure.

c) Monitoring of silver eel runs on key rivers; assessment of the impact of restricted elver migration on the subsequent numbers of female silver eels.
Data: Numbers per month, per year; age & size structure of males and females.

d) Electrofishing surveys of selected rivers with eels as the target species. Population estimation by catch depletion methods, using at least 3 repeated fishings.
Surveys repeated at 2 year intervals.
Data: Numbers m^{-2}, Biomass g m^{-2} with confidence limits; Age & size structure, sex ratios.

e) Monitoring of eel stocks in estuaries and coastal waters (using methodology developed to monitor marine fish stocks).
Data: Size & age structure, sex ratios.

f) Commercial catches: further attempts need to be made to obtain accurate catch returns, or catch data, from commercial fishermen. This may require purchase of catches from selected fishermen (or fishermen chosen at random).
Data: Numbers caught - annual variation, seasonal variation, regional variation. Size & agestructure, sex ratios.

g) Development of models to assess the impact of natural and fishing mortality on the different life stages of male and female eels, and to predict the effect of changes in elver recruitment and fishing mortality.

APPENDIX A.

Extract from EIFAC/XVIII/94/Inf.5 (1994)

ANNEX F

OUTLINE OF RESEARCH AND MONITORING REQUIREMENTS

Jan Klein Breteler and Willem Dekker

During the Eighth Session of the EIFAC *Working Party on Eel* the measures required for a comprehensive research programme for the management of eel stocks and fisheries were discussed. The major questions confronting scientists and the required research to answer them are set out blow, under headings corresponding to the life stages of the eel.

The first step would be the appointment of a coordinating group to agree on priorities and propose a more detailed programme.

1. OCEANIC STAGES

a. Did oceanic hydrography change in such a way since the early 1980s that larvae and/or leptocephali recruitment on continental shelf of Europe or return of silver eels diminished ?

   - literature study
   - use of existing data on hydrography (inventory of sources)
   - comparison to Cod & Climate Conference

b. Did the quality of water in the Sargasso Sea suddenly change in the early 1980s ?

   - literature study
   - inventory of sources
   - analysis of existing data

c. Is there only one stock ?

   - genetics study
   - sampling programme European scale

2. RECRUITMENT TO GROWTH STAGE (GLASS EELS AND ELVERS)

a. Does stock-wide overfishing occur ?

- sampling programme on a European scale (stratified)
- focus on peak migration
- quantify catch and exploitation level locally
- quantify and qualify growth environment locally
- estimate level of allowable exploitation, i.e. without detrimental effect on local spawner production
- co-ordination on stock-wide scale

b. To which level has anthropogenic intervention reduced available suitable environment ?

1. Barriers
- experiments with different stages of elvers
- height, slope, texture of passes
- attracting streams (location, ratio to flux etc.)

2. Sampling programme on European scale
(this logically follows 1, which determines the characteristics of suitable environment)
- reference to historical period (early this century)
- quantification of available suitable environment currently under-utilised
- stock-wide coordination

3. GROWING STAGES (YELLOW EEL)

a. To what extent have existing habitats been degraded ?

1. Experiments on factors affecting local population densities, including validation in field
- substrate
- structure/vegetation
- food
- water quality
- bottom quality

2. Analysis of factors influencing growth
- available data (existing subgroup on growth)
- experimentally

3. Monitoring of environmental quality on European scale
- reference to historical period (as early as possible, 1950s, 1960s ?)
- quality both with respect to growth and density
- centralised co-ordination

b. Does stock-wide overfishing occur ?

- assessment of local fisheries on local scale
- integration to stock-wide level (because of local differences, this will necessarily be of much less detail than the best assessed areas)

4. SPAWNER ESCAPEMENT, SILVER EELS

a. To what extent and in what way do artificial barriers impede migration ?

- quantification of effect of migration barriers
- quantification of number of migration barriers
- improvements, deflection utilities etc.

b. What effect do contamination and parasites have on spawning prospects ?

1. Experimental approach
- focus on fat soluble contaminants and/or *Anguillicola*
- variable levels of contamination/infection
- experimental simulation of migration expenditure
- experimental simulation of oceanic conditions (swimming distance, time, pressure, etc.)
- contamination of spawner products of artificiallymatured eels

2. Monitoring of spawner quality stock-wide
- PCBs etc.
- *Anguillicola*
- stock-wide co-ordination

c. What effects will the stocking of glass eels from other catch areas have on spawning prospects ?

- experimental approach

d. In what way do sex ratios of silver eels vary throughout the habitat ?

- survey of literature
- enhanced sampling

e. What is the level of spawner escapement ?

- local sampling programmes
- stock-wide overfishing
- stock-wide co-ordination

APPENDIX B.

Eel population densities in 7 NRA Regions and Scotland obtained from NRA (WA) fish survey reports and some scientific publications. Data for the Severn-Trent Region are given in Table 6. Eel population densities: Occ = number of sites with eels/total number of sites surveyed; N $100m^{-2}$ and kg $100m^{-2}$ values are based on sites containing eels only.

1. **NRA Northwest Region**

River	Occ.	N $100m^{-2}$	S.E.	Min.	Max.
1971					
Caldew	2/5	4.0			
1991					
Lune	93/141	2.22	0.29	0.10	13.60
1992					
Bela	34/38	3.89	1.01	0.35	33.75
Leven	10/54	1.57	0.83	0.12	8.48
Ribble	15/42	3.56	0.93	0.50	12.50
Weaver	13/109	4.34	2.84	0.10	36.00
Wyre	31/45	5.49	1.08	0.20	28.75
1993					
Calder	15/18	7.30	3.47	1.42	54.17
Crake	23/24	10.39	6.80	0.32	159.24
Duddon	18/32	2.11	0.48	0.63	9.47
Ehen	30/32	4.52	0.90	0.27	22.76
Gowy	15/38	4.93	0.60	1.10	8.30
Hodder	39/70	2.19	0.36	0.15	8.80
Wirral (brooks)	2/23	11.50	10.50	1.00	22.00

2. NRA Northumbria & Yorkshire

A. Occurrence data only:

River	1991	1992	1993
Aln	9/9	17/18	11/13
Blyth	9/9	8/8	3/5
Coquet	3/6	9/10	8/11
Tyne, main	-	1/1	9/9
Tyne, North	12/13	41/42	38/42
Tyne, South	10/11	6/10	16/21
Wansbeck	10/10	16/17	6/7
Wear	10/10	14/18	10/15

B. Occurrence data and population densities:

West Beck (R.Hull)	Occ.	Mean	S.E.	Min.	Max.
1988 N $100m^{-2}$	2/2	23.2	--	4.7	41.7
kg $100m^{-2}$	2/2	2.22	--	0.59	3.85
1989 N $100m^{-2}$	9/9	32.34	10.10	1.20	93.8
kg $100m^{-2}$	9/9	2.64	0.70	0.18	7.15

C. Other rivers (Aire, Calder, Rother, mid/upper Don)

Sparse numbers of eels present because of polluted nature of the rivers (Dr S.Axford, NRA, pers.comm.).

3. **NRA Welsh Region**
(Turnpenny, 1983)

North Wales	Occ.	Mean	S.E.	Min.	Max.
N 100m^{-2}	8/25	18.50	11.40	1.00	96.00
g 100m^{-2}	8/25	0.61	0.16	0.11	1.25
Mid Wales					
N 100m^{-2}	5/25	6.40	0.26	2.00	16.00
g 100m^{-2}	5/25	0.44	0.15	0.14	0.86

Mean weight (g) per eel = 77.638 (S.E. 9.97).

4. **NRA Southern Region**

River	Occ.	Mean	S.E.	Min.	Max.
Test 1991-91					
N $100m^{-2}$	9/9	8.5	3.4	0.2	29.9
kg $100m^{-2}$	9/9	1.19	0.47	0.11	3.60
Arun 1990-93					
N $100m^{-2}$	6/6	12.4	5.0	3.2	25.4
kg $100m^{-2}$	6/6	0.83	0.20	0.39	1.62
Rother 1991-93					
N $100m^{-2}$	10/10	8.0	6.0	0.3	6.1
kg $100m^{-2}$	10/10	0.43	0.15	0.03	1.53
Cuckmere 1992					
N $100m^{-2}$	3/3	4.1	1.4	2.0	6.6
kg $100m^{-2}$	3/3	0.32	0.10	0.22	0.52
Pagham Rife 1992					
N $100m^{-2}$	1/1	4.9			
kg $100m^{-2}$	1/1	0.69			
Adur 1991-93					
N $100m^{-2}$	8/8	14.6	8.5	0.3	63.6
kg $100m^{-2}$	8/8	0.84	0.33	0.03	2.98
Ouse 1990-91					
kg $100m^{-2}$	5/5	0.67	0.16	0.26	1.07

5. **NRA Southwestern Region**

River	Occ.	Mean	S.E.	Min.	Max.
ISLE OF WIGHT 1993					
Medina	3/3				
N $100m^{-2}$		11.1	2.0	7.3	14.1
kg $100m^{-2}$		1.74	0.49	0.76	2.29
Eastern Yar	4/7				
N $100m^{-2}$		19.3	6.1	1.0	3.7
kg $100m^{-2}$		1.73	0.34	1.06	2.68
HANTS/DORSET					
Avon 1990	3/3				
N $100m^{-2}$		3.0	1.5	0.6	5.8
kg $100m^{-2}$		0.55	0.21	0.19	0.93
Dockens 1990	1/1				
N $100m^{-2}$		2.67			
kg $100m^{-2}$		0.14			
Frome 1990	6/6				
N $100m^{-2}$		11.2	2.0	4.1	16.7
kg $100m^{-2}$		1.20	0.12	0.81	1.53
Mill Stream 1967	1/1				
N $100m^{-2}$		314.0			
kg $100m^{-2}$		2.94			
Sydling 1970	1/1				
N $100m^{-2}$		5.2	1.2		
Piddle 1990	3/3				
N $100m^{-2}$		6.9	1.5	4.6	9.7
kg $100m^{-2}$		0.76	0.38	0.29	1.50
Stour 1992	30/30				
N $100m^{-2}$		1.2	0.2	0.1	4.8
kg $100m^{-2}$		0.31	0.06	0.01	1.33

NRA SOUTH WESTERN REGION - continued:

River	Occ.	Mean	S.E.	Min.	Max.
SOMERSET 1990					
Bristol Frome	6/7				
N $100m^{-2}$		11.7	0.7	0.1	4.4
kg $100m^{-2}$		0.19	0.08	0.01	0.51
Bristol Avon	8/8				
N $100m^{-2}$		0.4	0.3	0.1	2.1
kg $100m^{-2}$		0.11	0.09	0.01	0.62
Frome	15/15				
N $100m^{-2}$		1.3	0.4	0.1	4.6
kg $100m^{-2}$		0.46	0.14	0.02	1.46
Avon tribs.	40/40				
N $100m^{-2}$		3.1	0.7	0.1	19.6
kg $100m^{-2}$		0.35	0.06	0.01	1.30
Congresbury Yeo	2/2				
N $100m^{-2}$		0.13		0.11	0.15
K. Sedgemoor	2/2				
N $100m^{-2}$		0.6		0.4	0.8
kg $100m^{-2}$		0.02		0.01	0.03
Washford 1992	1/1				
N $100m^{-2}$		5.2			
kg $100m^{-2}$		0.28			
Arvill 1992	3/3				
N $100m^{-2}$		1.6	0.5	0.9	2.6
kg $100m^{-2}$		1.52	0.47	0.84	2.42
Horner 1992-93	6/6				
N $100m^{-2}$		20.0	4.6	2.5	30.4
kg $100m^{-2}$		0.55	0.14	0.12	1.09
Brue & tribs.	36/36				
N $100m^{-2}$		10.5	2.7	0.1	9.41
kg $100m^{-2}$		0.55	0.10	0.01	2.25
Axe & tribs.	30/30				
N $100m^{-2}$		12.0	2.8	1.7	45.0
kg $100m^{-2}$		1.12	0.20	0.15	2.91
B-Taunton canal	11/11				
N $100m^{-2}$		3.1	2.4	0.5	8.4
kg $100m^{-2}$		0.45	0.09	0.06	1.12

NRA SOUTH WESTERN REGION - continued:

River	Occ.	Mean	S.E.	Min.	Max.
YEO-PARRETT					
Parrett	42/42				
N $100m^{-2}$		10.5	3.0	0.1	104.1
kg $100m^{-2}$		0.83	0.18	0.02	3.39
Yeo & tribs.	35/35				
N $100m^{-2}$		3.9	0.9	0.1	22.6
kg $100m^{-2}$		0.38	0.08	0.01	2.44
Tone & tribs.	8/8				
N $100m^{-2}$		1.6	0.6	0.2	5.0
kg $100m^{-2}$		0.39	0.08	0.23	0.62
DEVON/CORN.					
Dart 1987	38/43				
N $100m^{-2}$		17.8	3.3	0.0	101.6
Tamar 1978	31/34				
N $100m^{-2}$		4.5	1.0	0.0	27.8
kg $100m^{-2}$		0.11	0.02	0.0	0.41
EXE & TRIBS.					
Upper Exe 1977	14/17				
N $100m^{-2}$		1.8	0.4	0.0	4.7
Culm 1981	21/22				
N $100m^{-2}$		25.3	9.6	0.0	211.6
kg $100m^{-2}$		0.82	0.30	0.0	6.45
Creedy 1978	8/12				
N $100m^{-2}$		6.2	2.5	0.0	26.6

NRA SOUTH WESTERN REGION - continued:

River	Occ.	Mean	S.E.	Min.	Max.
Otter 1978	12/12				
N $100m^{-2}$		15.7	2.6	6.1	28.2
Teign 1979	13/15				
N $100m^{-2}$		7.0	2.4	0.0	35.3
kg $100m^{-2}$		0.07	0.01	0.0	0.16
Lyn 1980	3/10				
N $100m^{-2}$		6.2	5.3	0.8	16.8
Mole 1983	21/21				
N $100m^{-2}$		8.4	1.7	1.0	36.4
Camel 1988	16/17				
N $100m^{-2}$		10.6	2.9	0.0	42.1
Torridge 1986	22/29				
N $100m^{-2}$		4.5	1.5	0.0	38.4
kg $100m^{-2}$		0.11	0.02	0.0	0.50
Taw 1987	4/4				
N $100m^{-2}$		21.0	10.2	2.1	49.7
kg $100m^{-2}$		0.20	0.07	0.06	0.38
Fal 1978	6/10				
N $100m^{-2}$		40.4	32.5	0.0	329.5
kg $100m^{-2}$		0.04	0.03	0.0	0.29
Hayle 1977	5/9				
N $100m^{-2}$		17.6	6.3	0.0	45.0
kg $100m^{-2}$		0.97	0.36	0.0	2.68
Plym 1982	14/14				
N $100m^{-2}$		25.3	41.6	0.8	157.4
kg $100m^{-2}$		0.39	0.06	0.09	0.81
Trenant 1982	5/5				
N $100m^{-2}$		13.8	10.6	1.3	56.3
kg $100m^{-2}$		0.35	0.17	0.08	1.02

6. **NRA Anglian Region**

River	Occ.	Mean	S.E.	Min.	Max.
Yare 1987	15/15				
N 100m^{-2}		3.9	0.8	0.6	11.3
kg 100m^{-2}		0.55	0.08	0.14	1.15
40 Foot 1990	13/13				
N 100m^{-2}		0.9			
kg 100m^{-2}		0.15			
Louth Nav. 1992					
N 100m^{-2}} e/f	7/7	7.8			
kg 100m^{-2}} e/f		0.70			
N 100m^{-2}} net	6/6	2.8			
kg 100m^{-2}} net		0.32			
Ancholme 1993					
N 100m^{-2}} e/f	6/6	1.0			
kg 100m^{-2}} e/f		0.22			
N 100m^{-2}} net	7/7	0.1			
kg 100m^{-2}} net		0.01			
Lincs. Drains 1982	?/45				
N 100m^{-2}		3.3	1.0	0.0	24.8
kg 100m^{-2}		0.25	0.08	0.0	1.91
Witham 1982					
N 100m^{-2}} e/f	11/11	3.0	1.0	0.2	9.4
kg 100m^{-2}} e/f		0.49	0.12	0.07	0.98
N 100m^{-2}} net	6/6	0.2	0.1	0.1	0.8
kg 100m^{-2}} net		0.01	0.01	0.01	0.06

NRA ANGLIAN REGION - continued:

River	Occ.	Mean	S.E.	Min.	Max.
NENE CATCHMENT					
Nene 1989					
N $100m^{-2}$} e/f	11/13	0.4	0.2	0.0	2.0
kg $100m^{-2}$} e/f		0.18	0.08	0.0	0.90
N $100m^{-2}$} net	20/47	0.15	0.02	0.0	0.4
kg $100m^{-2}$} net		0.02	0.01	0.0	0.11
Ise 1989	1/5				
N $100m^{-2}$		0.1			
kg $100m^{-2}$		0.05			
Harpers Brook 1992	1/5				
N $100m^{-2}$		0.35			
kg $100m^{-2}$		0.04			
Willow Brook 1989	6/9				
N $100m^{-2}$		0.9	0.5	0.0	3.0
kg $100m^{-2}$		0.28	0.14	0.0	0.87
Moreton's Leam '92	2/2				
N $100m^{-2}$		0.8			
kg $100m^{-2}$		0.08			
Holland Drains '91	1/1				
N $100m^{-2}$		4.0			
kg $100m^{-2}$		0.57			

7. **NRA Thames Region**

Location	N 100m^{-2} Min.	Max.
A. Naismith & Knights (1993)		
Estuary tributaries	0.6	113.9
Other tributaries	0.0	4.0
River Thames	0.0	6.0
B. Data from NRA Thames -749 sites		
ca. 549 sites:	0.0	0.001
ca. 200 sites:	over 0.001	

8. **Scotland**

River	No. sites	Mean	S.E.	Min.	Max.
A. MILLS (1970)					
Eden Water 1969	5				
N 100m^{-2}		132.4	26.8	40.0	197.0
kg 100m^{-2}		3.27	1.08	0.79	6.10
Eden Water 1970	1				
N 100m^{-2}		44.4	2.9	3.6	48.0
kg 100m^{-2}		1.05	0.14	0.89	1.46
B. HUSSEIN (1981)					
Tweed tribs:					
Eden Water					
N 100m^{-2}		93.0			
kg 100m^{-2}		3.28			
Leet Water					
N 100m^{-2}		36.0			
kg 100m^{-2}		2.16			
Eddleston Water					
N 100m^{-2}		20.0			
kg 100m^{-2}		0.85			
Leader Water					
N 100m^{-2}		13.0			
kg 100m^{-2}		0.36			

APPENDIX C.

Summary of information on the swim bladder parasite *Anguillicola crassus* (Nematoda).

The nematode parasite *Anguillicola crassus* is causing increasing concern amongst commercial eel fishermen. The NRA Anglian Region is currently carrying out a study of the problem, so this section is confined to a summary of the published information on the parasite in the U.K.

This parasite occurs in the swim bladder of the European eel but it is a native parasite of *Anguilla japonica* Temminnck & Schlegel in Japan. It was first observed in Europe in 1980 but has since spread rapidly, probably as a result of the extensive movement of eels within and across national boundaries for the purposes of stocking aquaculture (Kennedy & Fitch, 1990).

It was first reported in Britain in late 1987, but by late 1988 gravid females were present in several rivers in eastern England. This spread is probably correlated with the movement of lorries in East Anglia associated with the exportation of eels to the continent, or with the import of eels into London (Pilcher & Moore, 1993).

The parasite needs an intermediate host, usually Copepoda (e.g. *Cyclops*,) but other invertebrates such as juvenile *Gammarus* (Amphipoda) have been implicated. Also other fish species, such as the smelt *Osmerus eperlanus* L., may be able to act as intermediate hosts (Pilcher & Moore, 1993) although the parasite may not reach the adult stage (De Charleroy *et al.*, 1990).

In the River Thames, a 12 to 32% variation in infection was observed during 1988 to 1992, shortly after the parasite was first detected in the U.K. (Pilcher & Moore, 1993). Parasite densities ranged from 1 to 5 nematodes per eel.

At present the impact of the parasite on U.K. or European stocks is not known. A commercial eel fisherman in East Anglia noted that, although the presence of the parasite did not affect its market value, he could lose up to 10% of his catch during transportation (verbal communication with the author). It has been suggested that the invasion of the parasite into eel swim-bladders could impair the migration of maturing silver eels back to the Sargasso Sea. However, there are no data to support or contradict this idea. Possible lessons may be learned from a study of the parasite in its original host, the Japanese eel *A. japonica*.

The parasite is now firmly established in the U.K. and, with present knowledge, it cannot be eradicated.

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