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Temporal changes in European eel, *Anguilla anguilla*, stocks in a small catchment after installation of fish passes

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Abstract Changes in the abundance of European eel, *Anguilla anguilla* L., in the River Frémur, France, were examined over an 8-year period. Natural connectivity of the river was disturbed by three high dams that inhibited eel upstream migration and reduced recruitment by elvers and yellow eels. After eel passes were installed, fish became more abundant upstream (mean density 0.5 eel m^{-2}). Moreover, except in the more upstream areas, no decline in eel numbers and biomass was found, in contrast to the general decline of eel throughout its distribution range. It was concluded that eel passes are important to conserve and/or to recover eel stocks.

KEYWORDS: abundance, *Anguilla*, eel passes, recruitment.

Introduction

European eel, *Anguilla anguilla* L., is an amphihaline catadromous fish species that migrates inshore to coastal waters, estuaries and streams, where it spends several years growing. Some eels stay in salt or brackish water along the coast while others penetrate rivers and streams to complete their growth (to the yellow eel stage) in fresh waters. Ibbotson, Smith, Scarlett & Aprahamian (2002) suggested that colonisation of freshwater habitats by the European eel occurs according to a simple dispersion model. However, the extent of inland waters colonised by eels depends more on the high behavioural plasticity of this species: some seem to stay in downstream reaches of rivers, whereas others colonise whole river systems (Feunteun, Laffaille, Robinet, Briand, Baisez, Olivier & Acou 2003). During the yellow eel growth stage, macro- and microscale factors, such as distance from the sea, depth and flow velocity, influence the spatial distribution and population structure (Lobon-Cervia, Utrilla & Rincon 1995; Ibbotson *et al*. 2002; Laffaille, Feunteun, Baisez, Robinet, Acou, Legault & Lek 2003; Laffaille, Baisez, Rigaud & Feunteun 2004).

The European eel can be numerically dominant in fish communities of many inland aquatic systems (Moriarty & Dekker 1997; Feunteun, Rigaud, Elie & Lefeuvre 1999). However, at least since the 1980s, the continental abundance of the European eel has declined throughout its distribution range (Moriarty & Dekker 1997; Lobon-Cervia 1999; Dekker 2003a). Since 1980, a general decline in glass eel immigration was observed that continued to 1990, then stabilised at a very low level of about 10% of the former level (Dekker 2003b). Latest observations suggest a further decline (Dekker 2003b). Landings of the yellow and silver eel fisheries have been in decline for several decades, at least since the mid-1960s (Dekker 2003b).

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Considering the recent scarcity of this species throughout its distribution range, the International Council for the Exploration of the Sea (ICES) recommended that all means should be taken to restore the depleted stocks, at all biological stages (ICES 2002). A stock recovery plan is urgently needed (ICES 1999). Whatever the reasons for the decline (overexploitation, changes in oceanographically condition, pollution, parasitism, degradation of freshwater habitats, reductions in accessible freshwater habitat, see for example Castonguay, Hodson, Moriarty, Drinkwater & Jessop 1994; Moriarty & Dekker 1997; Feunteun 2002; Dekker 2003a; Kirk 2003), Russell & Potter (2003) suggested that the principle of the precautionary approach is directly relevant to the management of the European eel stock. The application of this approach includes management of freshwater, estuarine and coastal habitats, including construction of passes at physical obstructions to migration (Legault 1988; Knights & White 1998), as dam construction has been identified as a major factor responsible for the severe reduction of freshwater eel stocks (Moriarty & Dekker 1997; Feunteun 2002).

The Frémur is a small river of northern Brittany (France). It is representative of many small coastal catchment in the Biscay region (see Feunteun *et al.* 1998; Laffaille *et al.* 2003). However, natural connectivity has been disturbed by several barriers, including three high dams that inhibit eel upstream migration and reduce recruitment by elvers and yellow eels. As one of the dams (Bois Joli) is 14-m high with a dry vertical wall, during migration it was totally impassable until it was equipped with a fish lift in 1992. Two of the downstream dams (Pont Avet, 6-m high and Pont es Omnès 4-m high) were partially impassable until they were equipped with eel passes in 1996 (see Feunteun *et al.* 1998): small eels (< 120 mm) could reach the upstream area without using the pass (Legault, Laffaille, Guillouët, Acou 2004). A particularity of these small individuals is their ability to crawl out of the water to bypass small obstructions (Legault 1988).

The aim of this study was to examine temporal changes in characteristic mean of eels (densities, biomass and eel length) over an 8-year period in the River Frémur after the passes were installed, to assess the efficacy of the passes in helping to conserve the freshwater stock of the species.

Materials and methods

The River Frémur is 17-km long and opens into the English Channel near Saint-Malo (Fig. 1). Its catchment area is about 60 km^2 and the overall length of the river and its tributaries is 45 km. The slope varies between 0.1 and 2%, with a mean of 0.6%. Despite its small size, the River Frémur contains a wide range of habitats from high velocity streams typical of the trout zone to lentic waters of the bream zone in downstream areas, man-made ponds and reservoirs, and wetlands. Fishing pressure is low with no commercial eel fisheries, and anglers focus on cyprinids, esocids and percids in ponds and reservoirs.

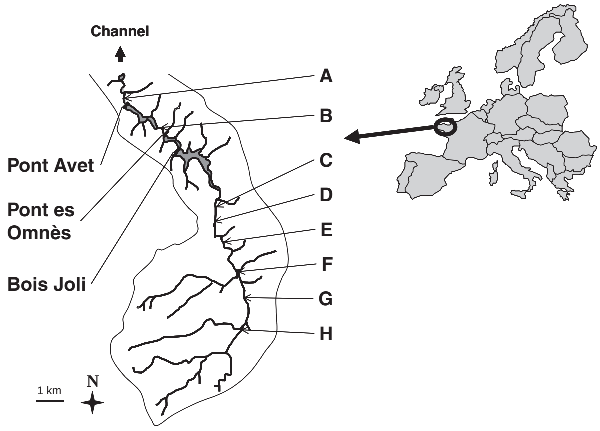

Figure 1. The Frémur catchment, main river sampling sections (from A to H), dams and eel passes.

Eel sampling was conducted annually by electric fishing in September from 1995 to 2002. An EFKO® electric fishing apparatus that delivered direct current (100–500 V and 0.8–10 A) was used. Eight river sections were sampled, located in the main stream between 4 km from the estuary and 17 km upstream. In September, the majority of tributaries have no flow. Water surface area sampled ranged from 430 to 1500 m^2. One river section was located downstream of the three dams (section A), one between Pont Avet and Pont es Omnès dams (section B) and the six others upstream of Bois Joli.

After the end of each sampling, eels were weighed (nearest g), measured (total length, mm) and released inside the sampled area.

The depletion method (Feunteun *et al.* 1998; Laffaille *et al.* in press) was used to assess fish abundance (expressed as number or g m^{-2}) (with a minimum of two electric fishing passes). Fishing efficiency was high (mean efficiency = 0.70 on the first electric fishing pass). The mesh size of the nets used was 3 mm.

In each river section, eel density (number m^{-2} and g m^{-2}) was related to year using exponential function: eel density = a exp ($b \times year$) where year was from 1

(1995) to 8 (2002). Similar regressions were explored between mean eel length (mm) at each river section according to year. Correlations were tested using *F*-tests. The exponential model was used because it was found to be more predictive than a linear model.

Results

A total of 7079 eels was collected. Eel total length ranged from 60 to 880 mm (mean ± SD = 251 ± 111 mm). Density ranged from 0.04 to 1.91 eels m^{-2} according to river section and year (mean ± SD = 0.46 ± 0.32 eel m^{-2}). Similarly, biomasses ranged from 1.04 to 73.19 g m^{-2} (mean ± SD = 15.45 ± 10.97 g m^{-2}).

With the exception of the upstream river section H, only small differences in eel densities (Table 1) were found between downstream and upstream reaches (*F*-test, $P > 0.05$). Eel density was only found to decline on average 16% per year in section H (Fig. 2). Eel biomasses showed similar trends (Table 2) but declines were observed in both sections G and H (average decline from 12 to 23% of biomass each year; Fig. 3). Mean size (Fig. 4) only declined significantly in upstream river sections (sections F and G) (Table 3), although these decreases were low (from 2 to 3% annually).

Table 1. Coefficients of the exponential function model between eel density (number m^{-2}) and year for eight river sections (from A to H) in the Frémur catchment

Section	*a*	*b*	r^2	*P*-value
A	0.448	0.128	0.31	NS
B	0.056	0.094	0.12	NS
C	0.712	0.012	0.01	NS
D	0.336	−0.012	0.01	NS
E	1.262	−0.079	0.28	NS
F	0.170	−0.096	0.15	NS
G	0.379	−0.159	0.37	NS
H	0.466	−0.161	0.86	< 0.01

Discussion

Several surveys of European elver or eel recruitment are available (Legault 1994; Dekker 2003b; Legault *et al.* 2004), but few have related recruitment trends to population dynamics (e.g. Vollestad & Jonsson 1988) and none aimed to conduct a long-term survey of the annual effects of restoration of migration pathways on

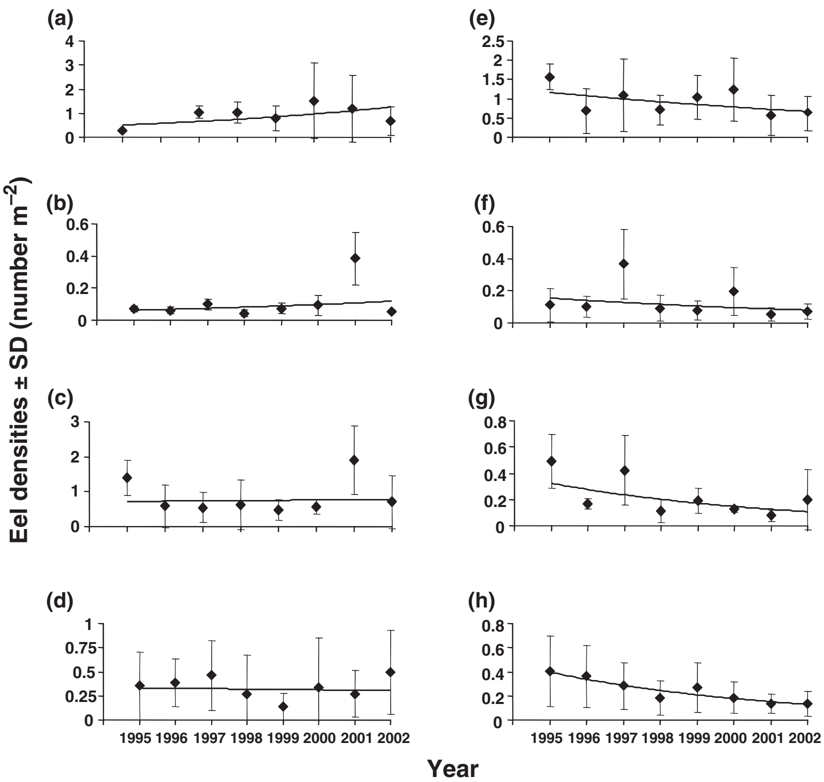

Figure 2. Change in eel density ± SD (number m^{-2}) with year in the eight river sections of the Frémur catchment.

Table 2. Coefficients of the exponential function model between eel biomass (g,m^{-2}) and year for eight river sections (from A to H) in the Frémur catchment

Section	*a*	*b*	r^2	*P*-value
A	25.76	0.045	0.02	NS
B	1.84	0.119	0.15	NS
C	12.95	0.022	0.01	NS
D	10.93	0.038	0.02	NS
E	32.22	−0.054	0.08	NS
F	12.56	−0.149	0.26	NS
G	15.15	−0.233	0.56	< 0.05
H	23.96	−0.124	0.80	< 0.05

the stock at the scale of the whole catchment. Despite the presence of hydraulic structures that reduce accessibility to upstream zones, the abundance of the eel population of the River Frémur seems high compared with other French (Chancerel 1994; Conseil Supérieur de la Pêche, personal communication; Laffaille *et al.* in press) and European rivers (Moriarty & Dekker 1997). However, very high densities rarely occurred and were generally the consequence of the concentration of small eels in sectors of riffles with a high cover of vegetated substratum (Laffaille *et al.* 2003) or immediately downstream from migration obstructions (Feunteun *et al.* 1998).

During this study, no significant decreases in eel densities were observed, except in the most upstream part of the catchment. Several hypotheses for the general decline of eel densities in Europe, as mentioned earlier, have been suggested (Castonguay *et al.* 1994; Moriarty & Dekker 1997; Feunteun 2002; Dekker 2003a; Kirk 2003). Loss of habitat, and especially that lost above barrages and dams (through the disconnection of available habitat from the stream), seem to be particularly responsible for the decline, or even extinction, of local populations (Chancerel 1994; Moriarty & Dekker 1997). Nowadays, migration of eels in many European rivers is obstructed by dams, and it is estimated that 33% of habitat within the natural range of species is not accessible for natural or artificial reasons (Moriarty & Dekker 1997). Although the situation varies between countries, over 90% of habitat is lost in Spain, and eel is expiated in more than 80% of river catchments across Spain, although it remains abundant in a few coastal streams whose waters flow unimpeded into the sea (Lobon-Cervia 1999). How-

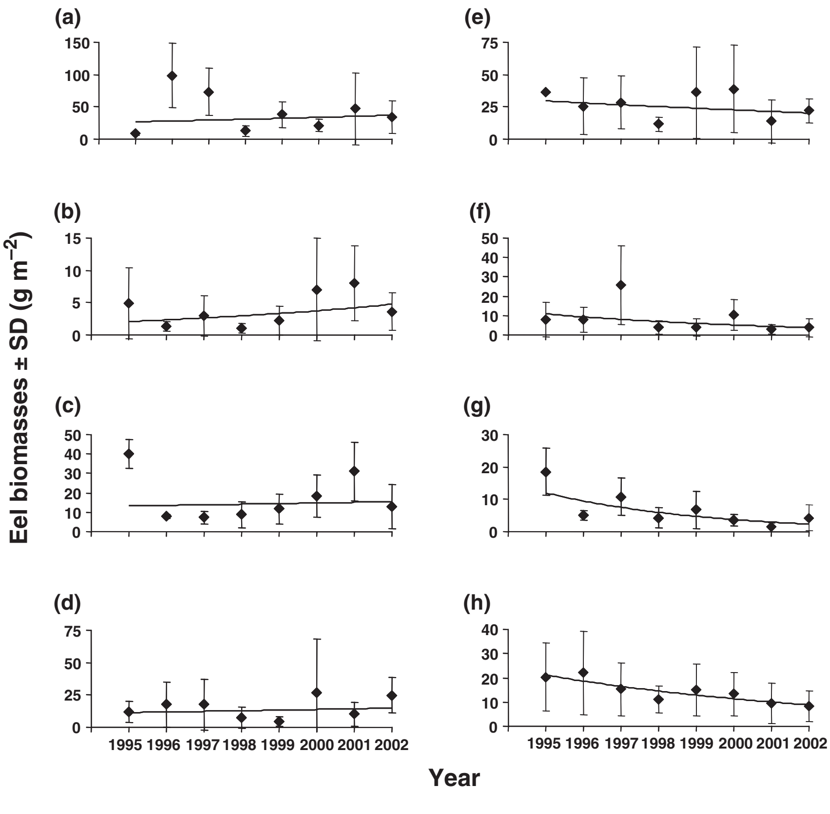

Figure 3. Change in eel biomass ± SD (g m^{-2}) with year in the eight river sections of the Frémur catchment.

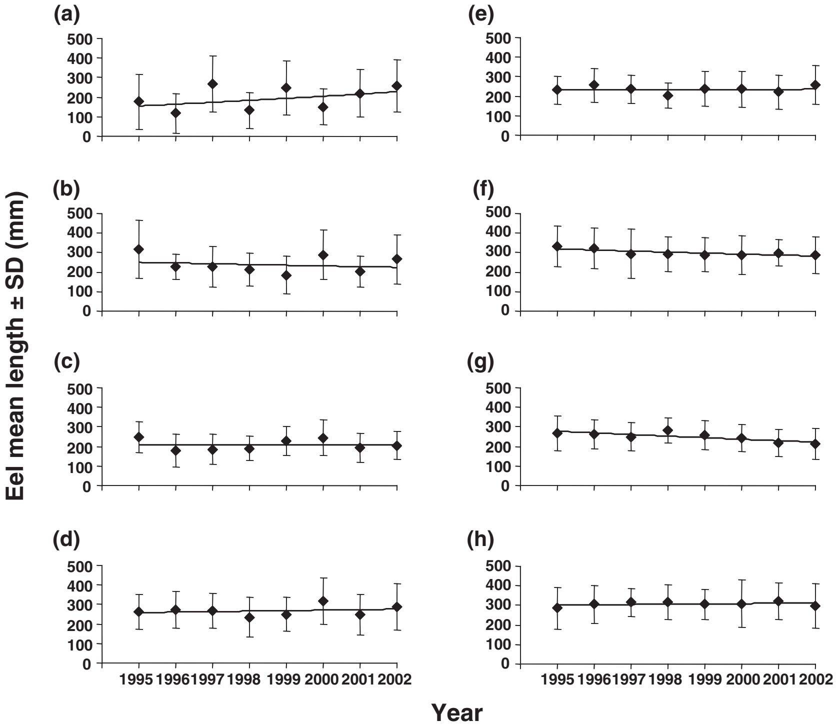

Figure 4. Change in eel mean length ± SD (mm) with year in the eight river sections of the Frémur catchment.

Table 3. Coefficients of the exponential function model between eel length (mm) and year for eight river sections (from A to H) in the Frémur catchment

Section	*a*	*b*	r^2	*P*-value
A	146.58	0.055	0.18	NS
B	254.15	−0.015	0.04	NS
C	206.57	0.001	0.01	NS
D	255.56	0.010	0.06	NS
E	232.52	0.002	0.01	NS
F	323.62	−0.017	0.60	<0.05
G	286.72	−0.032	0.64	<0.05
H	299.61	0.005	0.10	NS

ever, eel is still an abundant fish in the central part of its distribution range, and, for example, eels represented more than 50% of the fish biomass in the freshwater-reclaimed marshes along the French Atlantic coast (Feunteun *et al.* 1999), and Magalhaes, Batalha & Collares-Pereira (2002) found eels in 95% of 166 sites in south-west Portugal, where they were the second most abundant species.

In the River Frémur more than 100 000 eels have been caught since the eel passes have been monitored (between 1997 and 2003; Legault *et al.* 2004). The average length of eels has declined in the upstream areas, but it is mostly small eels (<120 mm) that recruit upstream of the dams, especially to Bois Joli (Legault *et al.* 2004). Although the presence of eels at Bois Joli before the passes were constructed suggests elvers can bypass the Pont es Omnès and Pont Avet dams, their construction has greatly improved access, and they are indispensable for colonisation of larger-sized eels (>120 mm).

The results of this study demonstrate the importance of maintaining longitudinal connectivity in rivers for elvers at a time of decreasing stocks. No decline in catches was observed in the River Frémur, despite a general decline elsewhere in Europe. The eel stock is outside safe biological limits and the current fishery is not sustainable (ICES 2001; Dekker 2003b), and it appears that anthropogenic factors, and especially habitat loss and dam construction, have negatively affected the stocks (Moriarty & Dekker 1997). Consequently, the formulation of a stock recovery plan is urgently needed (ICES 2001). Collares-Pereira & Cowx (2004) showed the role of catchment scale environmental management in freshwater fish conservation. At the catchment scale, eel passes are indispensable to conserve and recover freshwater eel stocks when the natural continuum is disturbed by hydraulic works. There is an urgent need to install eel passes in all hydraulic structures that disrupt recruitment and decrease habitat availability, and evaluate their effects.

Acknowledgments

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