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Optimal management of European eel in the Imsa River, Norway

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In the Imsa River, Norway, all upstream and downstream movement of eels has been continuously monitored since 1975. In this study the yield of the 1975 year class was calculated, and the effect on yield of various simulated management schemes, different levels of natural mortality, and different catch efficiencies for silver eels was evaluated. With high catch efficiencies for silver eels, a yellow-eel fishery will lead to a lower total yield in weight and a lower total value. With catch efficiencies for silver eels under 50%, introduction of a yellow-eel fishery will increase yield. If a yellow-eel fishery is to be introduced, age at recruitment to the fishery should be as high as possible. Yellow-eel fisheries will reduce the yield of silver eels, especially in situations with low growth rates and low natural mortality rates, whereas the yield of yellow eels will be relatively unaffected by changes in age at recruitment.

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Introduction

The population dynamics of European eel (*Anguilla anguilla* (L.)) has been studied in the Imsa River, Norway, for a number of years (Vøllestad and Jonsson, 1986, 1988). In this river system all ascent (i.e., recruitment) and descent (i. e., emigration) are monitored by use of permanent traps, enabling all essential population parameters to be estimated. This paper concentrates on evaluating optimal management schemes for this eel stock by tracing the fate of a specific year class of eel at various levels of fishing intensity at the yellow-eel stage, and with different ages of recruitment to the yellow-eel fishery. Optimal management is evaluated both in terms of yield in weight and in terms of total value using simple catch models. Such an evaluation has previously been made for the eel stocks in two Italian lagoons (Gatto *et al.*, 1982; Ardizzone and Corsi, 1985). However, these authors had to assume a constant rate of recruitment, an assumption which is clearly not valid (Moriarty, 1986; Dekker, 1986; Vøllestad and Jonsson, 1988). No such assumption is necessary for the Imsa River eels.

Materials and methods

Study area

The study was carried out in the Imsa River, southwestern Norway. The catchment area is 128 km^2, of which 12% is lake surface. For further details see Vøllestad and Jonsson (1986, 1988). All ascending and descending fish are caught in permanent traps set at the outlet and controlled at least twice daily. Seaward-migrating silver eels are caught in a Wolf trap (Wolf, 1951) at the river's mouth (trap inclination 1:10; apertures 10 mm). All ascending eels larger than 25 cm are caught in this trap, thus providing a 100% catch of descending silver eels. This trap, together with an accompanying elver trap and a salmon ladder ending in a capture chamber have been in continuous operation since 1975. All ascending elvers and small yellow eels are caught in the trap. The traps are serviced at least daily. A small-scale commercial silver eel fishery is established in the river, and its catches are reported annually to the Research Station for Freshwater Fish at Ims. No yellow-eel fishing occurs on a regular basis, and the catch by sports fishermen is negligible. Silver eels descend the river in autumn, usually between September and November (Vøllestad *et al.*, 1986)

Methods

The total number of emigrating silver eels of the 1975 year class was estimated from the total number of emigrating silver eels in the years 1975–1987, and the observed mean age distributions of silver eels during 1982–1987. The instantaneous rate of natural mortality for yellow eels (M_Y) was that calculated for the 1975 year class (0.225), because of the completeness of the data set for this year class; it was assumed constant with

Table 1. Mean weight (g) of the various age groups of yellow eels, and male and female silver eels, estimated number of yellow eels of the 1975 year class (N_i) and estimated number of emigrating silver eels of the same year class (N_s) from the Imsa River ($M_Y = 0.225$, $F_Y = 0$, $q_s = 1.0$).

	Mean weight				
Age	Yellow	Male silver	Female silver	N_i	N_s
0[a]	0.4			42 945	0
1	4.3			34 313	0
2	18.2			27 416	0
3	47.1	117		21 950	22
4	92.9	105	294	17 484	153
5	150	114	295	13 806	459
6	211	129	355	10 664	911
7	267	108	402	7 793	1 559
8	320		411	4 981	1 537
9	366		440	3 124	1 341
10	424		441	1 623	714
11	528		468	798	342
12[b]	729		845	367	117
13[b]	812		1 073	190	58
>14[b]	995		1 126	92	73

a: Age 0 denotes elvers.
b: Numbers for ages 12, 13 and > 14 were estimated from the age distributions of the silver eels given by Vøllestad and Jonsson (1988).

respect to age. This value of M_Y is at the upper limit of the range reported by Vøllestad and Jonsson (1988), but the effect of smaller values closer to the mean is examined in the analysis described below. Mean weights at age for silver and yellow eels were calculated from a pooled sample for the years 1982–1987. Most of the relevant data are summarized in Table 1. The methods are described in more detail by Vøllestad and Jonsson (1988).

In this fishery all silver eels are harvested, and there is no yellow-eel fishery. The total yield from the 1975 year class is therefore the cumulative catch over the years of emigrating silver eels of that year class. To evaluate the effect of introducing a yellow-eel fishery in the Imsa River, the effect on silver-eel catch and mean weight of the eels in the silver- and yellow-eel fishery was assessed allowing for different intensities of yellow-eel fishing mortality (F_Y) and different ages at recruitment to the yellow-eel fishery (t_R). The effect of different catch efficiencies for silver eels (q_s) on total yield was also evaluated.

The outcome of these simulated management schemes is given both in terms of yield in weight (Y_{kg}) and total value in Norwegian kroner (Y_{NOK}). The distinction between Y_{kg} and Y_{NOK} is necessary because yellow and silver eels fetch different prices. Average prices for ungraded fish (30 NOK kg^{-1} for yellow eels, 40 NOK kg^{-1} for silver eels) are used, though there is some size-dependent variation in the prices for the two kinds of eels.

The simulations use Baranov's simple catch equation (Ricker, 1975) for Type II fisheries where F_Y (the instantaneous rate of fishing mortality for yellow eels) and M_Y occur concurrently:

$$C_Y = N_Y F_Y A_Y / Z_Y \qquad (1)$$

where C_Y is the simulated catch of yellow eels, N_Y is the available number of yellow eels at the start of the season, Z_Y is the instantaneous rate of total mortality of yellow eels ($Z_Y = F_Y + M_Y$), and A_Y is the annual mortality rate of yellow eels ($A_Y = 1 - e^{-Z_Y}$).

In the calculations it is assumed that eels which were due to metamorphose and emigrate were not available to the yellow-eel fishery, and that the percentage of eels transforming from yellow to silver eels each year was unaffected by the changes in the management scheme. Thus the silver-eel catch each year is calculated as a percentage of N_Y each year (according to the observed age at which eels of the 1975 year class turned silver; Table 1), and it is assumed that the silver-eel mortality is negligible prior to capture. Silver eels are rarely caught in gears set for catching yellow eels, and it is assumed that premetamorphosing yellow eels also change behaviour during the last summer before emigration. Yellow-eel fisheries are most commonly carried out during summer, since the catchability of yellow eel is strongly correlated with both the level and rate of change of water temperature (Vøllestad, 1986). It is assumed that the growth rate is unaffected by changes in F_Y.

The eel stock

The eel stock is described in detail by Vøllestad and Jonsson (1986, 1988). Only the data most pertinent to this work are summarized here. The mean number of ascending elvers each year between 1975 and 1987 was 20 296 (range 2457–48 615), and was significantly correlated with the water temperature during ascent. The mean number of descending silver eels between 1975 and 1987 was 5417 (range 3574–8543). The survival rate of eels in fresh water (in the yellow-eel stage) is regulated by density-dependent factors. It is suggested that these density-dependent effects appear when elver numbers exceed a threshold of ca. 20 000. The instantaneous rate of natural mortality (M_Y) for the 1975 to 1979 year classes varied from 0.088 to 0.225. The instantaneous growth rate for weight for yellow eels decreased from 1.4 in the first growth season in fresh water to 0.2 for the seventh growth season onwards. The age of silver eels varies from 3 to 18 years (overall mean 7.9 years). The male:female ratio is 5:95, with some year-to-year variation. Mean length and weight of male silver eels are 405 mm and 110 g. Mean length and weight of female silver eels are 615 mm and 410 g. Mean annual production is 3.51 kg ha^{-1}, and mean yield is 2.27 kg ha^{-1}, equivalent to mean yield per recruit (elver) of 115.6 g.

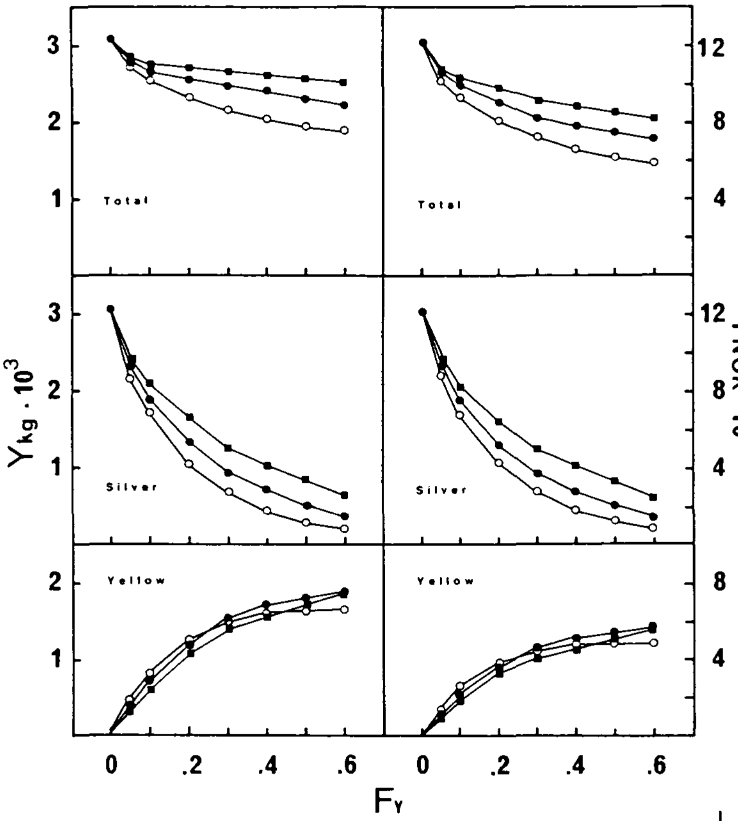


Figure 1. Variation in yield in kg (Y_{kg}) and total value in Norwegian kroner (Y_{NOK}) of the 1975 year class under different levels of yellow-eel fishing (F_Y) and with different ages of recruitment to the yellow-eel fishery (○ $t_r=3$; ● $t_r=4$; ■ $t_r=5$). (Upper panels: total yield; middle panels: silver-eel yield; lower panels: yellow-eel yield).

Results

Current situation

The cumulative total catch of silver eels of the 1975 year class (with $F_Y = 0$) was 3058.6 kg (7286 individuals) (Table 1), with an economic value of 122 344 NOK. This gives a yield per recruit of 71.2 g, and a yield per hectar of 2.64 kg. The mean total annual yield of silver eels in the period 1975 to 1987 was 2622.2 kg, giving a yield of 2.27 kg ha^{-1} or 115.6 g $recruit^{-1}$. More details on production and yield of various year classes are given by Vøllestad and Jonsson (1988).

Yield with variable fishing mortality and age at recruitment

Given the current situation with a catch efficiency (q_s) for silver eels of 1.0, the most efficient management scheme would be to fish only the silver eels (Fig. 1). Even low values of fishing mortality for the yellow eels will lead to a drastic reduction both in silver-eel yield and total yield. If any yellow-eel fishing were to be allowed, the age at recruitment to the fishery (t_R) should be at least age 5^+. Varying the age at recruitment has only a small effect on the yield of yellow eels, whereas the adverse effect of the yellow-eel fishery on the silver-

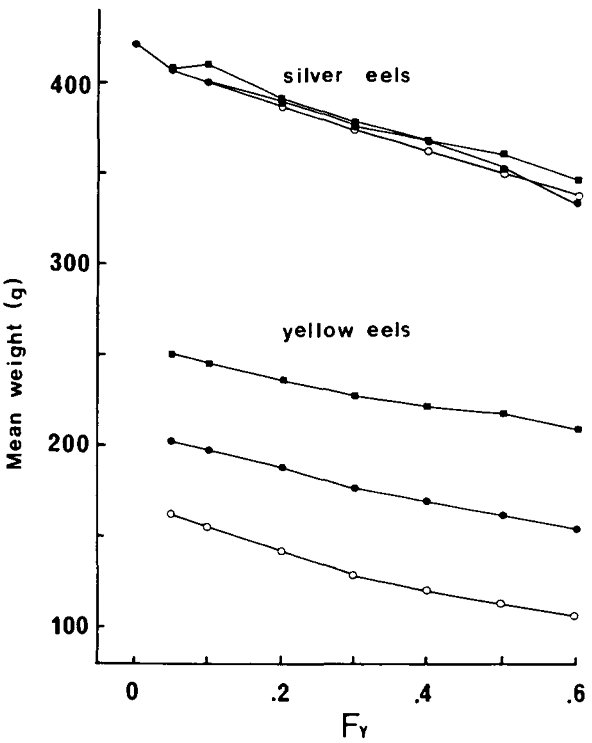


Figure 2. Variation in mean weight (g) of the catch of silver and yellow eels with varying levels of fishing mortality (F_Y) and different ages at recruitment to the fishery (○ $t_r=3$; ● $t_r=4$; ■ $t_R=5$).

Figure 3. Variation in yield in kg (Y_{kg}) and total value in Norwegian kroner (Y_{NOK}) of the 1975 year class as a function of yellow-eel fishing mortality rate (F_Y) and different catching efficiencies for silver eels.
Age at recruitment to the yellow-eel fishery is set at t_R=3.

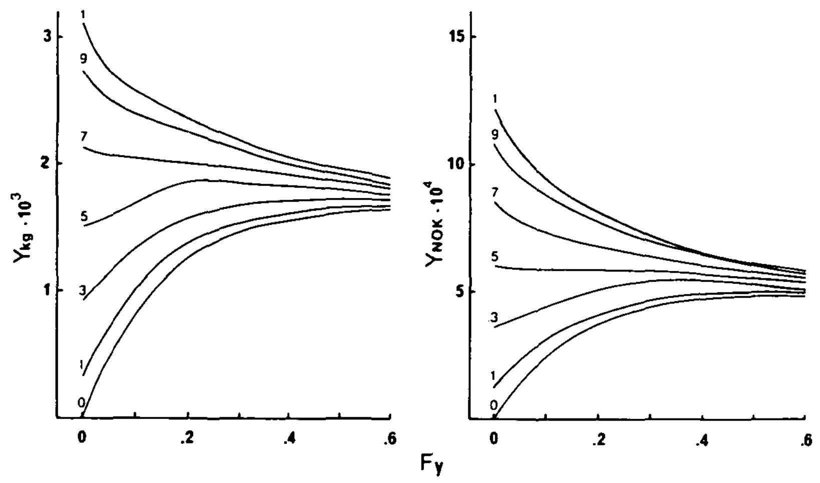
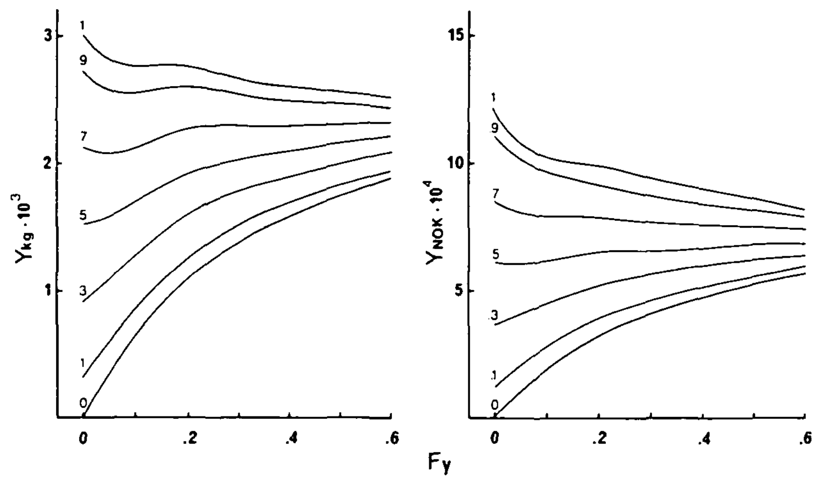


Figure 4. Variation in yield in kg (Y_{kg}) and total value in Norwegian kroner (Y_{NOK}) of the 1975 year class as a function of yellow-eel fishing mortality rate (F_Y) and different catching efficiencies for silver eels.
Age at recruitment to the yellow-eel fishery is set at t_R=5.



eel fishery is reduced by increasing the age at recruitment. Increasing the fishing mortality beyond 0.4 will only give marginal increases in yield of yellow eels, because the catch is shifted successively towards smaller specimens (Fig. 2). Increasing the age at recruitment will result in an increased mean weight of the yellow eels, whereas no effect on the mean weight of the silver eels was apparent.

Effect of varying the catch efficiency for the silver eels

Low age at recruitment to the fishery (t_R = 3).
For catch efficiencies for the silver eels over 0.5, the introduction of a yellow-eel fishery will lead to a reduction of yield in weight and of total value (Fig. 3). For catch efficiencies under 0.5 a yellow-eel fishery producing a fishing mortality rate of about 0.3 seems to be appropriate. Increasing the fishing mortality rate further does not lead to increases in total value, even if yield in weight does increase somewhat. This is because more of the total catch comprises yellow eels fetching lower prices than the silver eels.

High age at recruitment to the fishery (t_R = 5)
Here the picture is somewhat more complicated (Fig. 4). For most catch efficiencies for silver eels (excluding $q_s > 0.7$), increases in the fishing mortality will lead to increases in yield in weight, and this is pronounced for catch efficiencies under 0.5. The total value, on the other hand, decreases with increasing fishing mortality at catch efficiencies over 0.7. For lower catch efficiencies, total value increases slowly with increasing fishing mortality.

Effect of differences in natural mortality

The foregoing calculations use the natural mortality rate of yellow eels estimated for the 1975 year class (M_Y = 0.225). The natural mortality varies for various year classes of yellow eels (Vøllestad and Jonsson, 1988).

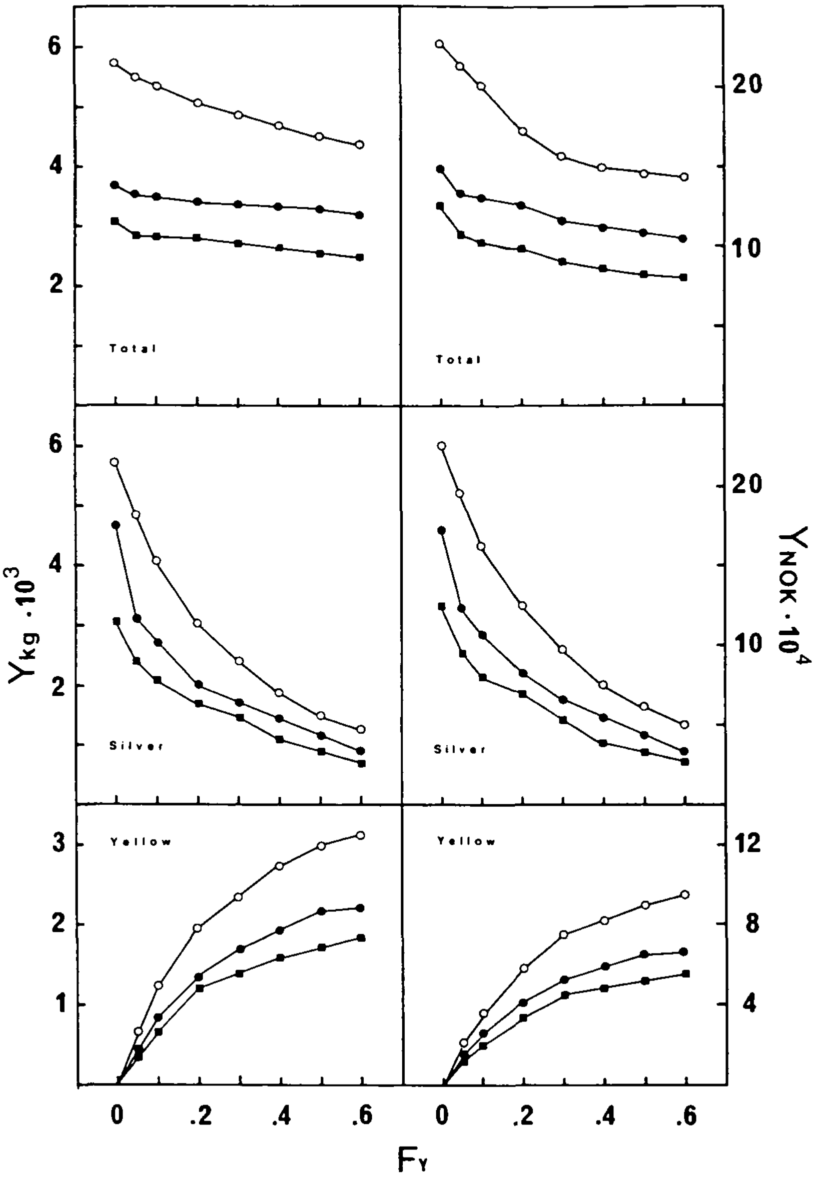


Figure 5. Variation in yield in kg (Y_{kg}) and total value in Norwegian kroner (Y_{NOK}) of the 1975 year class with different levels of natural (O $M_Y = 0.14$; ● $M_Y = 0.19$; ■ $M_Y = 0.225$), and fishing (F_Y) mortality. Age at recruitment to the yellow-eel fishery is set at $t_R=5$. (Upper panels: total yield; middle panels: silver-eel yield; lower panels: yellow-eel yield).

The effects of such differences in natural mortality have been examined in simulations using values of M_Y of 0.14 and 0.19 to cover most of the variability actually observed. The calculations use an age at recruitment to the fishery of 5 years, since this was the most favourable age (of those tested) at which to allow fish to enter the yellow-eel fishery.

The effect of variations in natural mortality was profound (Fig. 5), the largest of course being a drastic reduction in yield (both in weight and in total value) with increasing M_Y. But in no case did the introduction of a yellow-eel fishery lead to increases in total yield. At low levels of natural mortality the introduction of a yellow-eel fishery causes a drastic reduction in both total yield and silver-eel yield. At high levels of natural mortality the total yield in weight was almost constant for all levels of yellow-eel fishing, whereas the total value decreased somewhat. The effect of the degree of variation in natural mortality used in these simulations was more pronounced than the changes in age at recruitment to the yellow-eel fishery.

Discussion

In the Imsa River all silver eels are captured. Given such a situation, the above calculations show that the introduction of a yellow-eel fishery will always lead to a reduction in total yield. Given the associated costs involved in conducting a yellow-eel fishery, the introduction of such a fishery would always be disadvantageous. Gatto *et al.* (1982) performed a comparable analysis for the Valli de Comacchio eel fishery. They concluded that the total harvested biomass and the total value could be increased by catching a certain quota of old yellow eels. The improvement was, however, marginal. Gatto *et al.* (1982) were not able to estimate the more interesting net value by including the costs associated with conducting the fishery, but since the total value increased by only 10 to 20 % it is likely that the net value would in fact decrease.

In most rivers the most common situation is that only a small percentage of the emigrating silver eels are caught. If these percentages vary, so will the optimal management of the eel fishery change. With catch efficiencies for silver eels in the range of 70 % to 100 %, neither the total value nor the total yield in weight is increased by introducing a yellow-eel fishery. This is most clearly shown with a low age of recruitment to the yellow-eel fishery. In Norway, the minimum legal size for yellow eels is 40 cm, corresponding roughly to age 4^+ in the Imsa River. In a mixed yellow- and silver-eel fishery it is evident that the minimum legal size for yellow eels should be greater. However, in a fishery where the catch efficiency for silver eels is very low, changing the minimum legal size does not lead to significant changes in total yield.

The magnitude of the natural mortality rate evidently has a profound effect on the total yield of the system. In all cases a fishery where only silver eels are harvested will be most profitable. At low levels of natural mortality the adverse effect of a yellow-eel fishery on total yield and, especially, on total value, is much higher than at high levels of natural mortality. In this study it is assumed that the growth rate is unaffected by the introduction of a yellow-eel fishery. Natural mortality is affected by density-regulating factors such as fishing mortality (Vøllestad and Jonsson, 1988); so may growth. Also, these parameters will vary considerably from place to place. The adverse effects of a yellow-eel fishery of a given intensity will be most conspicuous when the growth rate is slow. This is simply because slower-growing yellow eels will be susceptible to capture for a longer time before they metamorphose into silver eels than more fast-growing eels.

To assess the requirements for the efficient management of an eel fishery, the most important parameters are the natural mortality rate, the growth rate, and the catch efficiency for silver eels. Having these data and also a knowledge of the costs associated with a yellow-eel fishery, it is possible to advise the fishermen on the most efficient management scheme. Of course, in most rivers there is also the problem of dividing the resource between different groups of fishermen. This political problem is superimposed upon the biological aspect discussed here.

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References

Ardizzone, G. D., and Corsi, F. 1985. Eel population structure, dynamics and fishing yield in a Mediterranean coastal lagoon. Oebalia, 11: 547–560.

Dekker, W. 1986. Regional variation in glass eel catches. An evaluation of multiple sample sites. Vie Milieu, 36: 251–254.

Gatto, M., Laniado, E., and Rossi, R. 1982. The management of eels in the Valli di Comacchio lagoon. Oceanol. Acta, 1982: 303–307.

Moriarty, C. 1986. Variations in elver abundance at European catching sites from 1938 to 1985. Vie Milieu 36: 233–235.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Bd Can., 191: 382 pp.

Vøllestad, L. A. 1986. Temperature-dependent activity of brackish water yellow eels, *Anguilla anguilla* L. Aquacult. Fish. Managem., 17: 201–205.

Vøllestad, L. A., and Jonsson, B. 1986. Life-history characteristics of the European eel *Anguilla anguilla* in the Imsa River, Norway. Trans. Am. Fish. Soc., 115: 864–871.

Vøllestad, L. A., Jonsson, B., Hvidsted, N. A., Næsje, T. F., Haraldstad, Ø., and Ruud-Hansen, J. 1986. Environmental factors regulating the seaward migration of European silver eels (*Anguilla anguilla*). Can. J. Fish aquat. Sci., 43: 1909–1916.

Vøllestad, L. A., and Jonsson, B. 1988. A 13-year study of the population dynamics and growth of the European eel *Anguilla anguilla* in a Norwegian river; evidence for density-dependent mortality, and the development of a model for predicting yield. J. Anim. Ecol., 57: 983–998.

Wolf, P. 1951. A trap for the capture of fish and other organisms moving downstream. Trans. Am. fish. Soc., 80: 41–45.