GROWTH AND PRODUCTION OF FEMALE YELLOW EELS (ANGUILLA ANGUILLA L.) FROM BRACKISH WATER IN NORWAY

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GROWTH
MORTALITY
BRACKISH WATER
NORWAY

ABSTRACT. — This paper describes the length distribution, age distribution, growth and production of female yellow eels caught with fyke nets in a small brackish water bight in the Oslo-fjord, Norway. Eels with lengths between 35 and 50 cm and ages between 4 and 7 years of age were most abundant in the catch. An instantaneous rate of total mortality of Z = 0.249, and an instantaneous rate of fishing mortality of F = 0.046 was found. Production was estimated to be from 51.2 to 98.9 kg ha^{-1}, and the production on biomass ratio (P/B) was calculated as 0.23.

ANGUILLA ANGUILLA
CROISSANCE
MORTALITÉ
EAU SAUMÂTRE
NORVÈGE

RESUMÉ. — Cette étude présente la distribution des tailles, l'âge, la croissance et la production d'Anguilles jaunes femelles capturées par verveux dans une petite baie saumâtre du fjord Oslo, en Norvège. Les Anguilles de taille comprise entre 35 et 50 cm et âgées de 4 à 7 ans sont les plus abondantes. Le taux instantané de mortalité totale est estimé à r = 0,249 et le taux instantané de mortalité par pêche à F = 0,046. La production est estimée à 51,2 — 98,9 kg par ha et le rapport production sur biomasse, à 0,28.

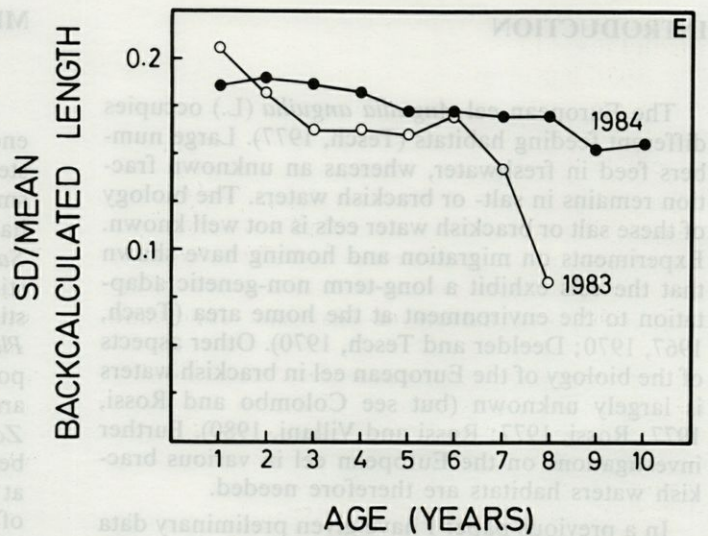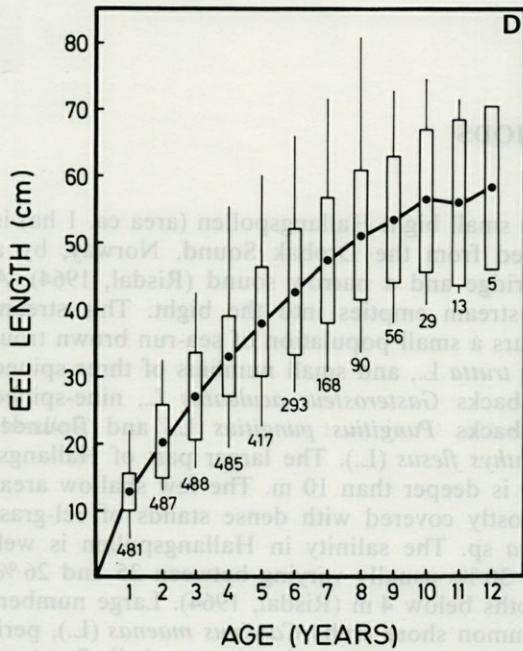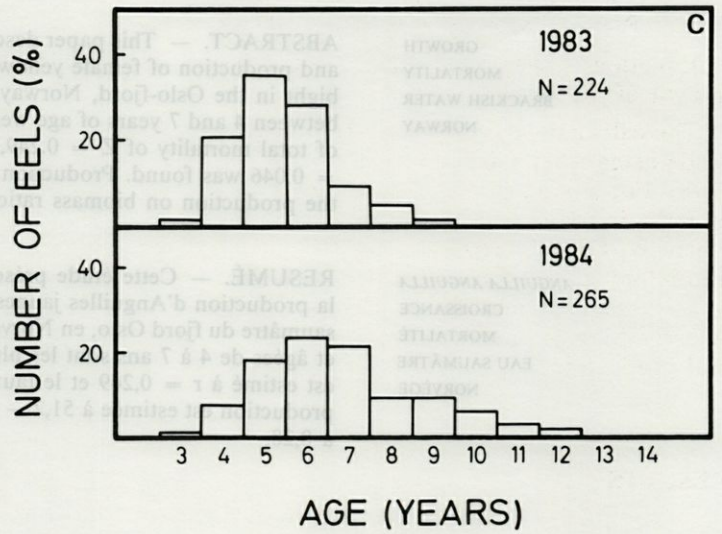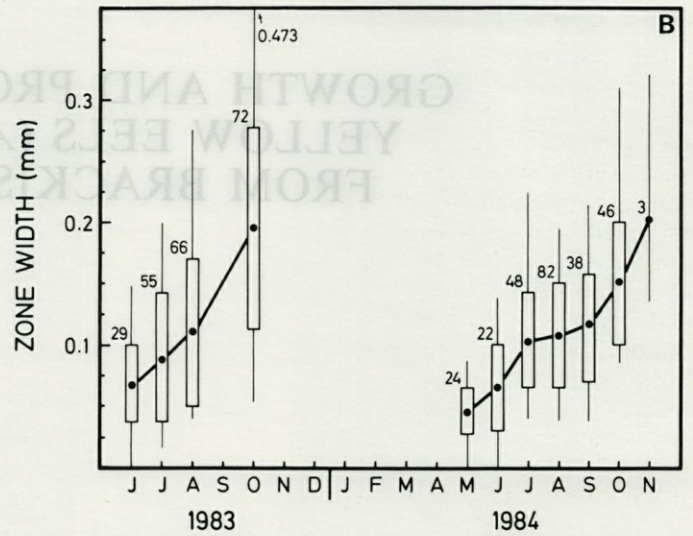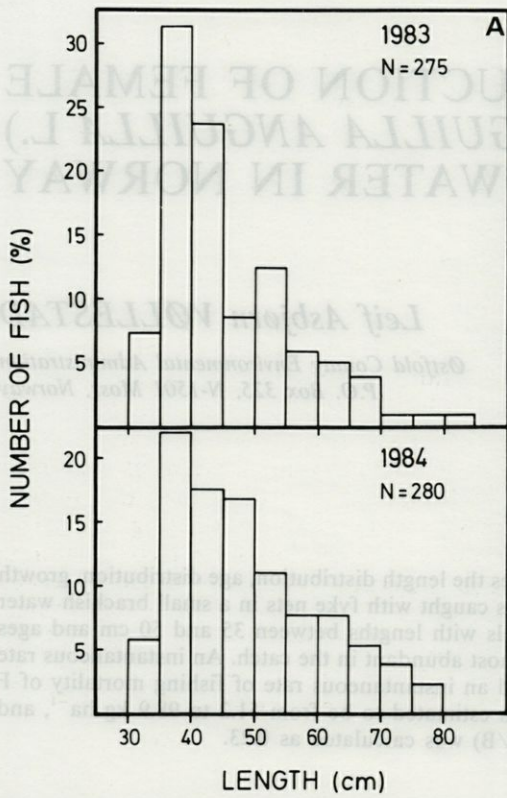## INTRODUCTION

The European eel *Anguilla anguilla* (L.) occupies different feeding habitats (Tesch, 1977). Large numbers feed in freshwater, whereas an unknown fraction remains in salt- or brackish waters. The biology of these salt or brackish water eels is not well known. Experiments on migration and homing have shown that the eels exhibit a long-term non-genetic adaptation to the environment at the home area (Tesch, 1967, 1970; Deelder and Tesch, 1970). Other aspects of the biology of the European eel in brackish waters is largely unknown (but see Colombo and Rossi, 1977; Rossi, 1977; Rossi and Villani, 1980). Further investigations on the European eel in various brackish waters habitats are therefore needed.

In a previous paper I have given preliminary data on the growth of female yellow eels in the small bight Hallangspollen, south-eastern Norway (Vøllestad, 1985).

METHODS

The small bight Hallangspollen (area ca. 1 ha) is enclosed from the Drøbak Sound, Norway, by a steep ridge and a narrow sound (Risdal, 1964). A small stream empties into the bight. This stream harbours a small population of sea-run brown trout *Salmo trutta* L., and small numbers of three-spined sticklebacks *Gasterosteus aculeatus* L., nine-spined sticklebacks *Pungitius pungitius* L., and flounder *Platichthys flesus* (L.). The larger part of Hallangspollen is deeper than 10 m. The few shallow areas are mostly covered with dense stands of eel-grass *Zostera* sp. The salinity in Hallangspollen is well below 30 ‰ usually varying between 25 and 26 ‰ at depths below 4 m (Risdal, 1964). Large numbers of common shore crabs *Carcinus maenas* (L.), periwinkles *Littorina* spp., and common whelk *Buccinum undatum* (L.) are found. The most abundant demersal fish species present were goldsinny *Ctenola-*

A 1983 N = 275

1984 N = 280

NUMBER OF FISH (%)

LENGTH (cm)

B

ZONE WIDTH (mm)

J J A S O N D J F M A M J J A S O N
1983 — 1984

C 1983 N = 224

1984 N = 265

NUMBER OF EELS (%)

AGE (YEARS)

D

EEL LENGTH (cm)

AGE (YEARS)

E

1984

1983

SD/MEAN BACKCALCULATED LENGTH

AGE (YEARS)

brus rupestris (L.), black goby *Gobius niger* L., eelpout *Zoarces viviparus* (L.), plaice *Pleuronectes platessa* L., and flounder *platichtys flesus.*

The eels were caught with summer fyke nets (10.5 mm bar mesh) (Moriarty, 1972). These nets catch eels larger than 30 cm (Vøllestad, 1985). The nets were monitored at uneven intervals, varying from every day to once a week. The eels were measured (total length (T.L.; 0.5 cm), weighed (1 g), and sexed by gross macroscopic examination of the gonads. All eels had the typical gonads of female yellow eels (Sinha and Jones, 1966). The eels were aged from sacculus otoliths using the clearing method (Vøllestad, 1985). The caudal otolith radius (Rossi and Villani, 1980; 0.01 mm), gives a relative measure of the body length of the eel. The linear least square regression of total length (L, cm; range 30.0 − 78.5 cm, mean = 48.3 cm, SD = 11.5 cm) on otolith radius (X, mm) was :

$$L = 2.186 + 25.80\, X, \ N = 274$$
$$R^2 = 0.78, \ F_{1,272} = 929, \ P < 0.001. \quad (1)$$

Equation 1 was used for back-calculating the growth of the eels.

The calculations of biomass and production were made using Allen's method (Allen, 1971; Chapman, 1978). For any age group, the instantaneous rate of increase in weight is $G = (\ln W_2 - \ln W_1)/t_2 - t_1$, where W_1 and W_2 are the average weights at time t_1 and t_2, respectively. Biomass is $B = \hat{N}W$, where $\hat{N}$ is the estimated number of eels in an age group. Average biomass is estimated as $\bar{B} = (B_{t1} + B_{t2})/2$, and production is estimated as $P = G\bar{B}$.

RESULTS

The length distribution of eels caught in the fyke nets did not differ between years (Fig. 1, A; X^2-test, $P > 0.05$). Eels with lengths between 35 and 50 cm were most abundant in the catch both years. Eels below approximately 37 cm in length were not fully vulnerable to the fishing gear.

The eels were aged from otoliths cleared in 96 % ethanol. The accuracy of the method was tested by comparison of the width of the outermost opaque zone during the summers 1983-1984 (Fig. 1, B). The zone width was narrow in May and June, and

increased through summer and autumn both years. This indicates that only one hyaline and one opaque zone were counted annually. If supernumerary zones (*sensu* Deelder, 1976) are present they do not occur at specific periods during summer. This further indicates that the ageing technique give a good estimate of the age of the eels.

The age distributions were significantly different for the two years (Fig. 1, C; X^2-test, $P < 0.01$). Year class 1978 was most abundant both in 1983 (age group 5^+) and in 1984 (age group 6^+). A larger number of old eels (> age 9) were caught in 1984 than in 1983.

The growth rate of the eels was rapid, decreasing somewhat with increasing age (Fig. 1, D). The variability in back-calculated length was high in all age groups. Calculations of the coefficient of variation (CV = standard deviation/mean) of the otolith size in each age group show that the relative variability is lower in the older ages (Fig. 1, E). This is probably due to emigration of the larger, maturing individuals in each age group. Back-calculated mean lengths in various age groups did not differ when back-calculation was compared for the individual year classes separately (tested with linear regression models and ANOVA, $P > 0.05$).

Mortality figures from the catch curves are difficult to obtain as emigration cannot be distinguished from the natural and fishing mortalities. Furthermore, the irregular year class strengths make estimation difficult. According to Ricker (1969, p. 10) the best way to reduce the effect of recruitment irregularities is to combine the samples of successive years. By doing this, relative numbers of eels in age groups 3 through 14 were obtained. Since age group, 3, 4 and 5 are not fully vulnerable to the fishery, only eels older than 5 years were used in the calculations. Simple catch curves (Ricker, 1975) were then fitted to the pooled data, giving an instantaneous rate of total mortality of $Z = 0.249$, and a survival rate of $S = 0.78$. The instantaneous rate of total loss from a stock is

$$Z' = Z + U = F + M + U,$$

where F is the instantaneous rate of natural mortality, M is the instantaneous rate of natural mortality and U is the instantaneous loss due to other causes (i.e. emigration) (Ricker, 1975). The recapture rate of tagged eels during 1983 was 4.1 %. Thus F can be estimated as $0.041 = F (1 - e^{-Z})/Z$ (cf. Gulland,

Fig. 1. — A, length distribution of female yellow eels *Anguilla anguilla* caught in Hallangspollen, 1983 and 1984. B, seasonal variation in width of the outermost opage otolith zone, standard deviation of the estimate when n > 5, and total range of variation of the measurements of female yellow eel *Anguilla anguilla* caught in Hallangspollen, 1983 and 1984. The number of otoliths measured is indicated. C, age distribution of female yellow eels *Anguilla anguilla* caught in Hallangspollen, 1983 and 1984. D, backcalculated mean lengths in each age group, standard deviation of the estimates, and total range of variation for female yellow eels *Anguilla anguilla* caught in Hallangspollen, 1983 and 1984. Number of eels used in the analysis is indicated for each age group. E, variability in mean otolith size in each age group (expressed as the coefficient of variation, CV = standard deviation of the estimate divided on the mean otolith size in each age group) for female yellow eels *Anguilla anguilla* from Hallangspollen 1983 and 1984.

Tabl. I. — Estimate of biomass (kg/ha) and production (kg/ha) of the eel population in Hallangspollen, Norway. The pooled age-distribution data for 1983 and 1984 and mean weights (g) in each age group is used. The number of eels present is estimated assuming that between 500-1000 eels older than age 5 is present. The number of eels in age group 3 through 5 are estimated using the estimated $M_{tot} = 0.22$.

Age	W	G	N̂	B	B̂	P
3	76.7		451-902	35.6-69.2		
		0.10			32.8-64.6	3.3-6.5
4	85.1		351-704	29.9-59.9		
		0.24			29.8-59.7	7.2-14.3
5	108.3		274-549	29.7-59.5		
		0.32			30.8-61.6	9.9-19.7
6	149.1		214-428	31.9-63.8		
		0.39			30.7-61.2	12.0-23.9
7	219.4		134-267	29.4-58.6		
		0.34			27.5-47.1	9.3-16.0
8	307.7		83-116	25.5-35.7		
		0.06			20.5-33.1	1.2-2.0
9	328.2		47-93	15.4-30.5		
		0.42			19.7-29.3	8.3-16.5
> 10	500.4		48-96	24.0-48.0		
				Σ B = 221.4-425.2		Σ P = 51.2-98.9

1969), giving $F = 0.046$. The instantaneous rate of natural mortality (M) and emigration (U) should therefore be $M + U = Z - F = 0.249 - 0.046 = 0.203$. It is not possible at this stage to discriminate further between natural mortality and emigration.

Precise information on the density of yellow eels in Hallangspollen was not obtained. In the coastal waters of Bohuslän, Sweden, a mean density of 700-7 000 individuals < 18 cm ha^{-1} was reported (Thorman and Fladvad, 1981). Allowing for mortality, a reasonable estimate may be that between 500 and 1 000 eels older than age 5 are present in Hallangspollen each year (eels older than age 5 are considered fully recruited to the fishery (see Fig. 1, C)). Using these figures, estimated total mortality rates, and mean weights in each age group, estimates of biomass and production for eels older than age 2 can be made (Table I). Total biomass (ΣB_i) was 221.4-425.2 kg ha^{-1}, whereas production (ΣP_i) was 51.2-98,9 kg ha^{-1}. The ratio of production on biomass (P/B) consequently was 0.23.

DISCUSSION

The age determination of eels is a matter of controversy (Deelder, 1976; 1981; Moriarty, 1983; Vøllestad, 1985). No methods for determining the age of eels are at present validated. The precision of the clearing method used in this study is described by Vøllestad (1985). In the present paper I present evidence that supernumerary zones are of no or only small importance. Thus I here present one piece of evidence for the method's validity (Beamish and McFarlane, 1983).

Annual "mortality" rates were calculated from the pooled age distribution. It is not possible to separate the effects of natural mortality and emigration due to maturation of the larger individuals in each age group, whereas fishing mortality can be assessed separately. A very low fishing mortality (F = 0.046) was found. This fishing mortality most probably is identical for all eels exceeding the minimum legal size (40 cm). The instantaneous rate of natural mortality (M) and emigration (U) was calculated to be 0.203. This is much lower than reported for the natural mortality alone for eels from brackish lagoons in Italy (Rossi, 1979). The natural mortality is probably highest in the younger age groups, decreasing for the older age groups. Emigration due to maturation, on the other hand, increases with increasing age and length. In the River Imsa in western Norway few female silver eels with lengths below 50 cm were reported (Haraldstad et al., 1985). The mean length of the yellow eels in age group 6 in Hallangspollen was 44.5-44.7 cm, thus only the larger eels in this age group will be ready to metamorphose. The mortality of eels younger than 6 years is unknown, but little fishing mortality or emigration due to maturation will occur.

Conservative estimates of the population density of eels in Hallangspollen resulted in a rather high estimate of production. A production of 51.2-98.9 kg ha^{-1} is over twice the production reported by Rossi (1979) for brackish water lagoons in Italy. It is in accordance with estimates from a small Danish stream (Rasmussen and Therkildsen, 1979), and is half that reported for small yellow eels (< 18 cm) from the Broälven estuary, Sweden (Thorman and Fladvad, 1981). Hopkins (1971) reported a production of 100-590 kg ha^{-1} of *Anguilla australis schmidtii* Phillipps and *Anguilla dieffenbachii* Gray in two small streams in New Zealand. Both Rossi (1979) and Rasmussen and Therkildsen (1979) reported production on biomass (P/B) ratios considerably higher than in Hallangspollen (0.47-0.57 vs. 0.23).

The P/B ratios in the New Zealand streams were also high (> 0.7) (Hopkins, 1971). Lower P/B ratios would be expected in the cold Norwegian waters compared to warm Italian lagoons and shallow Danish and New Zealand streams. This indicates that the high production in Hallangspollen is due to the high initial density, indicating that this estimate may have been too high. Further studies are necessary to clarify this matter.

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