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Long-term survival and growth of stocked eel, *Anguilla anguilla* (L.), in a small eutrophic lake

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Abstract
Decreasing populations of eel in Denmark have lead to studies of the feasibility of enhancing local eel stocks by restocking. This study reports on growth, survival and increase in biomass of wild and cultured eel, stocked in 1988 and 1989, respectively. Alcian blue marks were used to distinguish cultured from wild eels. Visual implant tags were used to measure growth of individual cultured eel. Based on a mark recapture estimate seven years after stocking, survival of the cultured eel was 42-57% and survival of the wild eel was estimated at 55-75%. From weight at catch, the increase in biomass of the cultured batch was estimated at 3.1-4.2 times the biomass initially stocked. The biomass of the wild batch increased between 10.4-14.1 times, about three times more than the cultured batch.

Keywords: *Anguilla*, visual implant tag, Alcian blue mark, stocking, small lake.

Introduction
Commercial catches of eels have decreased for several decades in Danish coastal and inland waters. The decline in eel fisheries is linked to a decrease in recruitment of eels to Scandinavia possibly starting in the 1940s (Hagström & Wickström 1990). A notable decrease in recruitment throughout Europe has been observed since the beginning of the 1980s (Moriarty 1990).

The possible causes of reduced recruitment include oceanic changes, overfishing, pollution, habitat degradation and man-made physical obstructions to migration (EIFAC 1993). Eel passes have been part of the Danish freshwater legislation since 1898 and are well managed. To sustain depleted stocks in Denmark the only present management option is transfer of glass eels from southern Europe where recruitment is still abundant (Moriarty & Dekker 1997).

Since 1987 a nation-wide eel-stocking programme in fresh and salt water has been in operation, financed by national funds and fish licence (Rasmussen & Geertz-Hansen, 1998). Because of low recruitment and to prevent spreading of the swim bladder nematode *Anguillicola crassus*, within-country transfer of juveniles for stocking was prohibited in the late 1980s. At the same time eel culture was developed and stocking material was commercially available from several Danish eel farms.

Stocking studies have been performed in drainable ponds (Dahl 1967, Klein Breteler *et al.* 1990). Studies have been conducted in streams where post-stock monitoring was possible by electrofishing (Bisgaard & Pedersen 1991, Berg & Jørgensen 1994). These studies, however, have been too short to assess the outcome of stocking in the long term. Few long-term studies have been undertaken (but see Wickström *et al.* (1996) and review by Knights & White (1998)). The present study was initiated in 1988 in a small closed lake in eastern Jutland with the objective to measure growth, survival and increase in biomass of stocked eel.

Material and methods

The study site, Lake Søndersø, (56°17'N, 10°49'E) was established in 1986 by damming up a meadow. The lake is 0.06 km^2 in size and has a catchment area of 0.6 km^2, consisting mainly of agricultural land. The lake is shallow with mean and maximum depths of 1.0 and 1.7 m, respectively. The water temperature in the lake in 1996 was measured to exceed 10°C from the end of April to the end of September with a maximum of 22°C in August. The lake is eutrophic with high phosphorus content throughout the year (0.1-0.5 mg total-P/litre) but low in ammonia (1.4-3.0 mg total-N/litre). During summer, about 90% of the lake is covered by submersed *Ceratophyllum* spp. (County of Århus 1997). Besides eel, the fish fauna consists of large numbers of crucian carp *Carassius carassius* (L.) and tench *Tinca tinca* (L.). The lake is closed to migration. A fish trap made to catch silver eels (mesh size 10 mm) is situated in the outlet of the lake and immigration of juveniles is not possible.

Table 1. Numbers stocked. Length, weight and condition.

Eel type/ year	n	Length, mean ± SD, cm	Length, range cm	Weight, mean ± SD, g	Weight, range, g	Condition ± sd, weight/length^3
Wild, 1988	1040	25.1 ± 2.4	15.5-31.0	19.2 ± 5.6	6.0- 33.0	0.120 ± 0.02
Cultured, 1989	1800	28.1 ± 4.5	15.0-40.0	39.2 ± 20.9	6.0-108.0	0.163 ± 0.01

The lake was stocked with wild and cultured eels in August 1988 and 1989, respectively (Table 1). The wild eels were not marked or tagged. The cultured eels stocked in 1989 were tagged with Visual Implant (VI) tags (Bisgaard & Pedersen 1991, Nielsen 1992). The tags were 3 mm long, 1 mm wide and 0.1 mm thick. Each tag was colour-coded and had a multidigit alphanumeric code. The tag was implanted subcutaneously, adjacent to the anal fin by use of hypodermic syringe. After implantation, the tag was visible but the code was in general illegible. Therefore the tagged specimens were additionally marked ventrally, approximately 3 cm posterior to the anus with an Alcian blue spot by use of a jet inoculator (Hart & Pitcher 1969).

Eels have been recovered from the fish trap and by fyke netting. Captured eels were killed and carefully examined for Alcian blue marks and VI-tags after removal of the skin. All examined eels were measured (0.5 cm), weighed (1 g) and sexed by gross morphology of the gonads (Sinha & Jones 1966).

In 1996 the total lake population was estimated by a mark-recapture estimate. In the beginning of June captured eels were marked by partial removal of the left pectoral fin and released. Examination of fin-marked eels was done on cumulated catch following three weeks of intensive fyke netting in October 1996. The population size and corresponding confidence limits were calculated by an adjusted Petersen estimate (Ricker 1975). Survival and instantaneous mortality was calculated as:

$$S = N_i / N_0 = e^{-Z_i},$$

where N_0 is the amount of stocked eels at year 0 and N_i is the estimated population i years later.

Results

Marks and tags

During the years 1990 and 1995-97 a total of 479 eels were caught, killed and examined for marks and tags. The marks and the tags were in most cases easy to detect, in the flesh, after the skin was removed. Random samples from 1995 to 1997 include 462 eels of which 255 eels were marked with Alcian blue. Of the marked specimens, tags were still present on 166 eels (Table 2). In nine specimens the tags were present without a mark. The proportion of cultured eels identified by the presence of a mark or VI-tags includes 264 eels corresponding to 57.1% of the lake population.

Table 2. Recaptured eels examined for Alcian blue marks and VI-tags.

Year	Sample, n	No mark, n	Mark, n	Tag, n
1995	148	67	81	48
1996	159	79	80	55
1997	155	61	94	63
Total	462	207	255	166

Size, growth and sex

Mean length of the wild batch (Table 3) was significantly higher compared to the cultured batch in 1995 and 1996 (*t*-test, $p<0.05$) but not in 1997 ($p>0.05$).

Mean growth of the cultured eels was 9.0 cm (range 4.5-16.5 cm) decreasing to a mean length increase of 4.4 cm, 4.0 cm and 3.6 cm per year, 6-8 years following stock-

Table 3. Length, weight and growth of wild and VI-tagged cultured eels, stocked in 1988 and 1989, respectively. Sampled during September and October (1996 sample from June).

Eel type/ year	Sample, n	Length, mean, cm	Length, range, cm	Weight, mean, g	Weight, range, g	Annual mean growth (range)
Wild						
1990	0	–	–	–	–	–
1995	67	60.9	29.0-75.0	424.7	35-781	5.1(1.4- 7.1)
1996	79	59.2	43.0-76.5	362.9	121-796	4.3(2.2- 6.4)
1997	61	57.6	33.5-80.0	318.6	40-891	3.6 (0.9- 6.1)
Cultured						
1990	17	38.4	30.5-45.5	98.6	47-150	9.0(4.5-16.5)
1995	48	54.5	38.5-67.5	283.0	84-560	4.4(2.6- 6.6)
1996	55	55.4	41.5-71.0	285.0	117-596	4.0(1.1- 6.0)
1997	63	57.5	42.0-71.0	320.2	92-675	3.6(1.8- 5.1)

ing. Annual length increase of the wild batch, calculated as mean sample length at catch/age was 5.1, 4.3 and 3.6 cm, 7-9 years following stocking (Table 3).

During the study only one male was recorded. It was recorded in the 1990 sample and was a cultured eel.

Survival

The population survey conducted in 1996 comprises a total of 788 fin-clipped and released eels. From a population sample of 326 eels taken four months later, fin clipping was recorded on 165 specimens. The total number of eels in the lake in 1996 was estimated to be between 1336 and 1808 specimens. From the identified proportion of cultured and wild eels the survival of the cultured batch was estimated at 42 and 57% corresponding to an instantaneous mortality of $Z = 0.12$-0.08 and the wild batch $S = 55$-75% corresponding to $Z = 0.07$-0.04.

Increase in biomass

From weight at catch in 1996 and weight at stocking the increase in biomass of the cultured batch was 3.1-4.2 times the biomass initially stocked. Biomass of the wild batch increased between 10.4-14.1 times, more than three times that of the cultured batch (Table 4).

Table 4. Population estimate 1996 (95% conf. limits) and estimated survival and biomass of stocked wild and cultured eel.

Eel type	Population estimate range, *N*	Mean weight ± s.d., g	Survival range, %	Biomass range, kg
Wild	601-814	363±131	55-75	217-294
Cultured	735-994	285±94	42-57	208-282

Discussion

Visual identification of Alcian blue marks on live specimens seems to be restricted to the first few years after marking (Dekker 1989, Pedersen 1998). The mark could, however, be identified by dissection of the eel eight years following marking. Unfortunately, no data on retention of Alcian blue marks is available. In a former study (Bisgaard & Pedersen 1991) retention of VI-tags was found to be 65 and 75% in two batches of eel. The present result showed retention rates of comparable size, 65% (Table 2) suggesting that loss of Alcian blue mark was small.

Contrary to external tags, e.g. Floy tags (Dekker 1989, Nielsen 1988), VI-tags seem not to affect growth negatively. Tagged specimens recovered after one year, increased in length between 4.5 and 16.5 cm with a mean of 9.0 cm (Table 3). Compared to other studies, growth of the tagged specimens was quite high. Mean values reported are in the range 2.4-6.5 cm/year decreasing with age (Rasmussen & Therkildsen 1979, Bisgaard & Pedersen 1991, Pedersen 1998), indicating that conditions for growth is favoured by environmental conditions such as high water temperatures and food availability and not negatively affected by VI-tags.

The observations of higher growth rate in the wild batch compared to the cultured batch contradict the result from a stocking study in a stream by Bisgaard & Pedersen

(1991). They found no difference in growth between stocked cultured eels and stream-dwelling wild eels, but survival of the wild eels was estimated to be twice that of the cultured eels. The survival may however be overestimated due to migration. In the present study the survival of the wild batch was (calculated from Z values) annually 4.4-4.9% higher compared to the cultured batch.

The estimated difference in biomass increase between the two types of eels is a result of both higher growth rate and higher survival rate of the wild eels. The difference may be caused by several reasons. The wild eels were stocked one year before the cultured ones and thereby may have gained an advantage in growth and survival in the virgin environment where food abundance was expected to be high. During the years 1991-94 small silver eels were caught in the fish trap (J. Guldholdt, pers. comm.) but no record is available from this period. Because of the relatively large size at stocking, a run of cultured males could have taken place in the first years after stocking (Wickström *et al.* 1996). Some wild eels were present in the canals draining the former meadow where the lake is now located (J. Guldholdt, pers. comm.). These could be included in the material of unmarked eels, affecting the estimate of survival and growth of the wild batch.

Few other studies present long-term data on survival rates. According to long-term records of stocked glass eel and exploitation in Lough Neagh, Ireland, a survival of 18% is regarded as minimum survival until exploitation at mean size 250 g (Moriarty & McCarthy 1982). Wickström *et al.* (1996) stocked two Swedish lakes with cultured juveniles of size 3-4 g; up to 14 years after stocking recaptures have been 11.3%, mainly as migrating silver eels in a mesotrophic lake and 1.7% in an oligotrophic lake. The difference possibly related to food abundance in the oligotrophic lake (Wickström *et al.* 1996). Vøllestad & Johnsson (1988) estimated survival between 26 and 50% from 13 years of data including natural ascent of elvers and descent of silvers, for five year classes, in River Imsa, Norway.

The somewhat higher estimate of survival in Lake Søndersø, between 42 and 75%, seems to be linked to the use of large yellow eels as seed stock in a virgin lake of high trophic level.

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