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Article · October 2017

DOI: 10.1016/j.fishres.2017.05.013

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Fisheries Research 194 (2017) 112–116

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Technical note

Survival and growth compared between wild and farmed eel stocked in freshwater ponds

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ARTICLE INFO

Handled by George A. Rose.

Keywords:
Anguilla anguilla
Growth increment
Mortality
Stocking

ABSTRACT

To evaluate the efficiency of eel stocking, we compared the survival and growth of wild eels (2–5 g) with that of "farmed" eels (3–6 g). Wild eels were caught in a river and farmed eels came from a farm, where wild imported glass eels are cultured. Two experiments of 5–12 month duration were conducted in a series of shallow, open ponds of approximately 200 m^2. Wild and farmed eels were batch tagged, mixed and released in the ponds at an initial density of 0.5 individual/m^2. Survival was rather high (34–88%) with variations between ponds. No significant difference in survival was found between wild and farmed during the first 5 month in both experiments. Growth rates were significantly higher for farmed eels compared to wild eels in both experiments. The results show that farmed eels performed better than wild eels. In regions with low recruitment the eel population may be increased by importing glass eels, stocked directly or stocked as on-grown farmed eel. The optimal size for stocking (between glass- and 3 g eels) may be determined through future studies.

1. Introduction

The European eel population has declined since early 1980's and the current recruitment of glass eel is only 1.2–8.4% of the 1960–1979 reference level (ICES, 2015). The cause of this decline is possibly a combination of loss of rearing habitat, fishing pressure, pollution, hydropower development, changes in oceanic conditions, introduced diseases and parasites and as a consequence of these, a decreasing spawning activity in the Sargasso Sea (Moriarty and Dekker, 1997).

To aid conservation/recovery of the eel stock, the European Council adopted a framework regulation (EU, 2007). The regulation requires EU Member States with eel habitats in their territory to implement national eel management plans at river-basin level with the objective to ensure the escapement to the sea of at least 40% of the silver eel biomass relative to the best estimate of escapement that would have existed if no anthropogenic influences had impacted the stock. One of the measures to meet the management target is stocking of juvenile eels; either caught wild or on-grown eels in aquaculture. On-grown eels from aquaculture, alias farmed eels, are commonly used for stocking especially in the Baltic Sea area (ICES, 2015). Sweden and Finland import glass eels and keep them in quarantine for ca. 9 weeks to confirm that they are not carrying any dangerous fish diseases and afterwards release them in open waters at size of 1.2 g (Wickström and Sjöberg, 2014). In Denmark eels have been stocked in rivers, lakes and estuaries in many decades to improve fishing. The Danish stocking program use imported glass eels, on-grown in commercial eel farms to a mass of 2–5 g. In Germany 5–8 g farmed eels are used (Simon et al., 2013). When using stocking as a management measure to conserve/improve the eel population, it is imperative to evaluate the outcome of this measure. Thus, Pedersen and Rasmussen (2015) estimated the feasibility of stocking farmed eels in a brackish Danish fjord. However, only few studies have aimed to evaluate if growth and mortality of farmed eels is comparable to that of wild eels (Rossi et al., 1988; Bisgaard and Pedersen, 1991; Pedersen, 2000; Simon and Dörner, 2013).These studies reach different conclusions but in general suggest that wild eels are better seed stock than farmed eels. In this study we aimed to compare initial growth and survival of wild and farmed eels of body mass 2–6 g under semi natural conditions in the first year after stocking.

2. Material and method

2.1. Experimental ponds

Ponds of approximately 200 m^2 (192–204 m^2), formerly used for rainbow trout (*Oncorhyncus mykiss*) farming, were cleaned during spring 2011 using an excavator. Vegetation and soft sediment from the bottom and sides of each pond was removed. The bottom of the pond was shaped with an inclination towards the outlet to facilitate efficient draining of the ponds. Well water was steadily supplied to the ponds to keep a stable water level. This was regulated by a monk sluice to keep a

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http://dx.doi.org/10.1016/j.fishres.2017.05.013
Received 8 March 2017; Received in revised form 17 May 2017; Accepted 19 May 2017

stable water depth of 0.9–1.1 m. Nets of 3 mm mesh size covered the outlet pipe at the monk to prevent eels to escape. These nets were regularly cleaned to keep a constant water depth. Water temperature in the ponds was measured using a temperature logger. The temperature varied from 4 to 20 °C and the cool groundwater feeding the dam kept the temperature within this range. In the winter time, the ponds were covered with ice during short periods.

The ponds swiftly developed into semi-natural systems with a diverse macrophytes community as well as a rich invertebrate and amphibian fauna. No food was applied during the experiments. No measures were taken to protect the ponds from fish predators such as grey heron (*Ardea cinerea*) and otter (*Lutra lutra*) and both species were observed in the vicinity of the ponds.

2.1.1. Experiments

Two replicate stocking experiments were carried out. The first experiment started in June 2011 and included 6 ponds. The second experiment started in June 2012 and included 7 ponds. The ponds used in the first experiment were reused in the second experiment and one additional pond was added to the second experiment.

2.1.2. Fish

The wild eels used in the study (Table 1), were captured in a trap, placed in an upstream eel-passage at Tange Hydropower Station in River Gudenå situated about 35 km from the Kattegat. The eels ascending the hydropower weir in June consist of both pigmented glass eels (0+ group) and older eels. Dahl (1983) studied the age of ascending eels at Tange Hydropower Station and found, from otolith analysis, that ages in the length group 12–16 cm used in this study, could vary from 1- 4 years.

The farmed eels (Table 1) were purchased from a commercial eel farm. The eel farm import glass eels from France and rear the eels to a size for human consumption. They also provide on-grown eels for stocking programs in Denmark and elsewhere. DTU-Aqua requires that eels used for stocking, are to be captured as glass eels during the previous winter and thus be maximum 8 months old when stocked.

The farm was controlled by DTU-Vet and was found free of the swim bladder nematode *Anguillicola crassus* and the viruses (infectious hematopoietic necrosis virus (IHNV); infectious pancreatic necrosis virus (IPNV); Viral hemorrhagic septicemia virus (VHSV).

2.1.3. Tagging

Both types of eels (wild and farmed) were batch tagged with standard length (1.1 mm × 0.25 mm diameter) Coded Wire Tags (CWT) using an automatic injector (Northwest Marine Technology MK IV). Prior to tagging the fish were sedated in a solution of 80 mg/l Benzocaine. Each eel was tagged by injecting a CWT into the dorsal musculature below the dorsal fin (Thomassen et al., 2000), giving each batch a unique code. Four different CWT batch codes were used to identify two types of eel (wild and farmed) in two different experiments (years).

2.1.4 Sampling procedure

The eels used in experiment **I** were sampled at two different points in time. Ponds 1–4 were drained in November 2011 and pond 6 and 7 were drained in June 2012. In experiment **II** all ponds were drained in November 2012. Some remaining eels from experiment **I** were recaptured when experiment **II** was terminated and the data are included in Table 2. Thus, there are data from 616 eels after 5 months, 94 eels after 12 months and 78 eels after 17 months.

When a pond was drained through the outlet pipe, a bag-net (3 mm mesh size) was used to intercept eels escaping with the outlet water. When the water depth in the pond was < 20 cm electrofishing was applied several times until all eels were assumed captured. After emptying the ponds, all captured eels were brought to the lab alive. Here the eels were euthanized by an overdose anesthesia (Benzocaine) and either frozen for later processing or processed right away. Euthanized eels were measured and weighed to nearest mm and 0.1 g. Frozen and thawed eels were corrected for shrinkage and mass loss according to the formula given by Simon (2013). In the lab, tags were dissected from the eels and stored for later identification of the CWT batch number. Reading the CWT was done using a light microscope magnifying zoom 20 − 40 times.

2.2. Data analyses

Growth increment was calculated for each pond and type of eel (wild and farmed) separately; Increment = (Lrecap − Lstock)/(Trecap − Tstock), where T is time and Lstock is the mean length/weight of the batch at release in pond X and Lrecap is the pooled mean length/weight in pond X.

The Fulton condition factor was calculated as $F = W(g)/L(cm)^3*100$ (Ricker, 1975). Statistical analyses were performed with the statistical program IBM SPSS statistics 21.0. The datasets met the assumption of normality and homogeneity of variance. Students *T*-test was used to compare mean mass and length of batches before stocking and the length increment between stocking and draining the ponds. The survival was analyzed using *chi-square* test.

3. Results

The ponds maintained a stable water level during the study period and no incidents of flooding or lacking water supply occurred. Flora and fauna developed quickly in the renovated dams and plenty of natural food was apparently available for the eels during the experiments.

Of the 1300 stocked eels, a total of 829 were recaptured at termination of the two experiments. In 41 eels (5%) the tag was either not located in the eel or lost during handling in the laboratory. Only eels with an identified tag (n = 788) are included in the analyses.

3.1. Growth and condition

To ensure maximum size similarity between the two groups, the selected farmed eels at time of stocking were shorter, but heavier than the wild eels. Thus, the initial mean mass and length of wild and farmed eels differ significantly (t-test, P < 0.001) in both experiments (Table 1).

In experiment **I**, the farmed eels increased more in both length and mass, compared to wild eels. The mean length increment during the first 5 month was 3.7 cm for the farmed eels and 1.5 cm for the wild eels, and after 17 months or two growth seasons, mean length increment of farmed eels was 11.6 cm (n = 213) significantly different (T-

Table 1
Length (cm), mass (g), biomass (g) and condition factor (F) of stocked wild and farmed eel (mean ± SD) in 2011 and 2012. Each pond had 100 individuals (50 wild and 50 farmed).

Year	Stocking date	Eel type	Length	Mass	Biomass	F	N
2011	June 7	wild	14.6 ± 1.3	3.2 ± 0.9	160	0.101 ± 0.013	300
2011	June 7	farmed	14.1 ± 1.1	4.0 ± 1.0	201	0.143 ± 0.014	300
2012	June 9	wild	15.7 ± 1.3	4.3 ± 1.2	214	0.109 ± 0.014	350
2012	June 9	farmed	15.2 ± 1.1	5.0 ± 1.2	249	0.140 ± 0.014	350

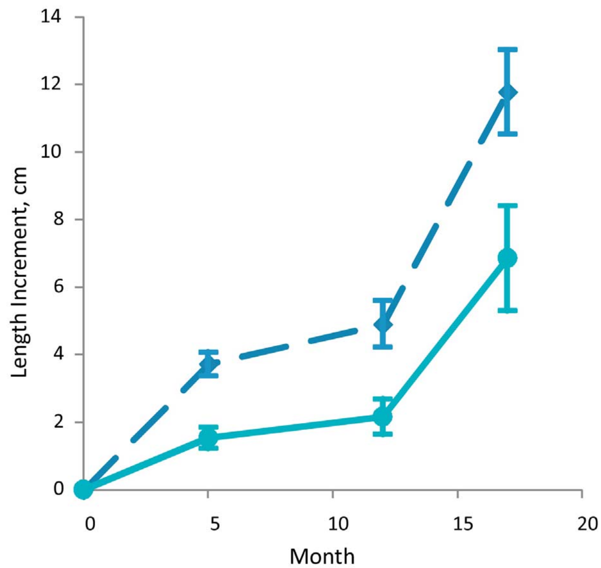

Fig. 1. Experiment I. Mean length increment of farmed (broken line) and wild eel (unbroken line). Confidence limits 95%, given by vertical bars.

test, P < 0.001) from the wild 6.7 cm (n = 174) (Fig. 1). The body condition of wild fish was from the start of the experiments lower compared to the farmed fish and stayed lower throughout the experiments (Tables 2 and 3). The condition increased during the experiment but continued to be low for the wild fish compared to farmed eel.

In experiment **II,** the length increment was small for both groups compared to experiment **I** (Table 3). However, the average length increment in experiment **II** was significantly different (T-test < 0.001) for farmed eel (1.1 cm) compared to wild eel (0.3 cm).

3.2. Survival

The number of recaptures is used as a proxy for survival from stocking to termination in order to compare between wild and farmed eel. In experiment **I** eels were collected up to 17 month after the start of the experiment (Table 4) .The overall survival was 71% (pond range 44–88%) for the farmed eels and 58% (pond range 34–80%) for the wild eels (Table 4). Regarding the first four ponds (i.e. pond 1–4) that was drained after 5 month, there was no significant difference (*chi-square, df 3, P = 0,162*), but for the two ponds (i.e. pond 6–7) drained after 12 month in June 2012 there was a significant higher survival of farmed eel (*chi-square, df 1, P=0,008*).

In experiment **II** (Table 4) survival after 5 months was 61% (pond range 46–82%) for farmed and 53% (pond range 32–70%) for wild eels and was not significantly different (*chi-square, df 6, P = 0,563*).

4. Discussion

4.1. Growth

The farmed eels grew significantly better than their wild conspecifics in both experiments (Figs. 1 and 2). The same growth capacity was expected since wild and cultured eels come from the same panmictic stock (Als et al., 2011). The farmed eels were imported from France to the farm as glass eels. Here they were size graded several times until tagged and released in the experimental ponds. Size grading is standard procedure in eel farms to separate fast growing individuals from slow growing individuals, since agonistic behavior of the larger eels prevent smaller eel to get food and gain weight (Knights, 1987). The possible effect of size grading on growth capacity was addressed (Anonymous, 1990), in a study where a cohort of pre-fed glass eels, were regularly size graded during a twelve month period. The results showed that eels may change speed of growth after grading. Thus, an initially slow growing eel could appear as one of the largest eels in the final size distribution and vice versa. It was concluded that size grading seem not to affect growth capacity.

Fish are able to increase their food consumption and growth rate during periods with excess food (Armstrong and Schindler, 2011) by adjusting food-processing; and the explanation for higher growth rate of farmed eel in the ponds may be that a high feeding rate in farmed eel has been retained after release in the ponds. However, these pond experiments were too short in time to show, if the farmed eel would change to a feeding rate comparable to the wild eel in the ponds. The wild eels in our study were older than the farmed eel. Dahl (1983) found the age could vary from 1–4 years and in comparison the farmed eel entered the farm as glass eel 3–6 month prior to stocking. However, it is reasonable to assume that length and mass increment is related to size and not age (Hamre et al., 2014).

The faster growth of farmed and wild eel in 2011 compared to 2012 might be explained by a higher water temperature in 2011; the mean temperature during the first five-months after stocking was about 0.65 °C higher in 2011 compared to 2012. Also a change in the quality as rearing ponds (food availability) from first to second year after the initial renovation of the ponds might explain the difference in growth between the two years. However, as we only compare directly between wild and farmed eels without year as predictor, no effect of year to year variation have influence on the conclusions. Other studies suggest similar growth of farmed and wild eels or that wild eels grow better. E.g. Rossi et al. (1988) raised young eel on artificial food in intensive rearing ponds, marked and released them at size 35–55 g in the Comacchio lagoon where natural eels were present. After 9 months of feeding in the lagoon, length increments of the reared and natural eels were found to be similar. Bisgaard and Pedersen (1990) stocked farmed eels 15–25 cm in a small stream where a wild population of eels were already present, and after 12 month the length increment of farmed eel did not differ from the wild stream dwelling eels of the same size. Based on analyses of otoliths from eels of size 60–80 cm, Lin et al. (2007)

Table 2
Total length (cm), mass (g) and condition factor (F) (mean ± SD) for wild and farmed in Experiment **I** (started 07. June 2011). The number of month after release indicate the time elapsed between stocking and recapture.

Recapture	Farmed, experiment I				Wild, experiment I			
*Month (date)	Length	Mass	F	n	Length	Mass	F	n
5 (Nov. 2011)	17.8 ± 1.9	8.3 ± 3.2	0.142 ± 0.015	119	16.1 ± 1.5	5.6 ± 1.7	0.129 ± 0.013	96
12 (June 2012)	19.3 ± 2.4	11.7 ± 4.9	0.160 ± 0.014	49	16.8 ± 1.9	6.3 ± 2.7	0.139 ± 0.023	45
17 (Nov. 2012)	25.9 ± 2.6	32.5 ± 12.1	0.170 ± 0.024	45	21.5 ± 4.5	17.0 ± 11.3	0.150 ± 0.014	33
Total				213				174

* Month = time spend in pond; date = time of harvest/draining.

Table 3
Length (cm), mass (g) and condition factor (F) (mean ± SD) for wild and farmed eel in experiment **II** (started 09. June 2012).

Recapture	Farmed, experiment II				Wild, experiment II			
*Month (date)	Length	Mass	F	n	Length	Mass	F	n
5 (Nov. 2012)	16.3 ± 3.9	6.6 ± 10.2	0.146 ± 0.022	215	16.0 ± 1.3	5.6 ± 1.6	0.134 ± 0.015	186

* Month = time spend in pond; (date) = date of harvest/draining.

Table 4
Recapture data as a percentage of numbers stocked in individual ponds. In Experiment **I** the eels are recaptured up to 17 month after release (see text). In Experiment **II** the eels are recaptured after 5 month.

	Experiment I		Experiment II	
Pond	Farmed (%)	Wild (%)	Farmed (%)	Wild (%)
1	62	54	74	56
2	72	34	46	40
3	82	76	58	60
4	76	80	66	46
5	–	–	54	70
6	44	60	82	68
7	88	44	50	32
Mean	**71**	**58**	**61**	**53**

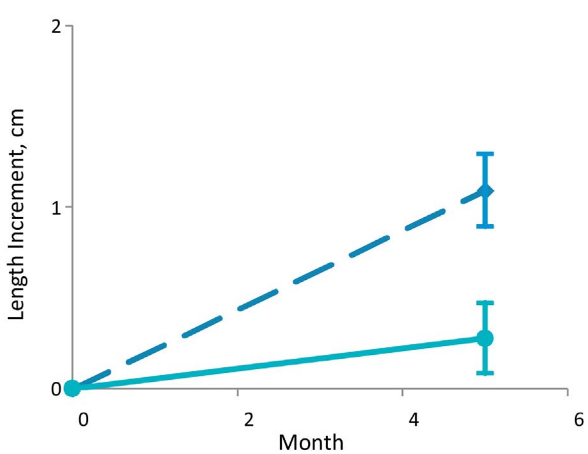

Fig. 2. Experiment II. Length increment of farmed (broken line) and wild eel (unbroken line). Confidence limits 95%, given by vertical bars.

found no difference in growth of wild and stocked eels in different habitats in Lithuania. However, Pedersen (2000) stocked a small lake with farmed and wild eels (15–40 cm) and after 6 to7 years wild eels grew to a greater body mass than the farmed eels did. The growth potential of farmed eel was poor in this experiment and may be explained by low quality eels from the farm. The higher condition factor of the farmed eels (Table 1) compared to the wild is likely a consequence of optimal temperature and food ad libitum in the eel farm. The increase in length, mass and condition of farmed eels found in this experiment suggests a good adaptation to the natural food items in the pond. Farmed eels having higher condition factor than wild eels was also seen in the study of Bisgaard and Pedersen (1991) (wild F = 0.11; farmed F = 0.15) similar to this study (F = 0.14; Table 1). In the study of Simon and Dörner (2013) the condition of farmed eels was comparable low, F = 0.12 which is close to the wild eels in this study. In a comparison between glass eels (0.27 g) and on-grown eels (6.6 g) Simon and Dörner (2013) concluded that the glass eels had a higher growth rate than farmed eel and after 3–5 years of growth had obtained the same size as the stocked farmed eels; suggesting that glass eels are better stocking material than farmed eels.

4.2. Survival

The ponds were drainable and the bottoms of the ponds constituted of gravel; however, it appeared to be a challenge to recapture all eels during draining and subsequent electrofishing and we found that recapturing all eels was indeed very difficult or impossible. Thus the recapture of X% of the stocked eels does not mean that there was a mortality of 100 − X%. "Missing" eels may have either died naturally, been predated or somehow avoided capture (buried in mud).

There was a rather high variation in relative survival from pond to pond (Table 4); some of this can be explained by different recapture efficiency because some ponds had deeper mud-layer than others. Another explanation is predation events, where birds or mammals might have successfully foraged in some ponds. Despite the variation between ponds, survival of farmed eel was not significantly different from survival of wild eels after five month in both experiments. In general, smaller fish have a higher mortality compared with larger fish (Ursin, 1967; Lorenzen, 1996) and this might partly explain why farmed eels have a higher survival after 12 months as the farmed and wild eel are significant different in mass (Table 2). Survival in the study of Rossi et al. (1988) was 98.6% of the wild eels and 84.8 and 90.1% for a slow growing and a faster growing group of the raised eels, respectively. A seven year stocking experiment performed in a newly established 6 ha lake with farmed eel of length 39.2 cm (SD 20.9) and wild eel of length 19.2 cm (SD 6.6) revealed that the wild eels survived better, at least 55% and farmed at least 42% (Pedersen, 2000).

4.3. Conclusion

Regardless of the underlying factors, this study demonstrated that stocking of on-grown eels of 3–5 g is feasible as they survive and grow at least as well as wild conspecifics. In Denmark eels are stocked in rivers, lakes and coastal waters. We believe the results are representative for the actual situation when eels are stocked in lakes, due to the open and natural status of the ponds used. The fact that we had a total of 13 replicates over two years, further validate the results.

To use stocking as a management measure in e.g. the Baltic countries where recruitment of young eel is low compared to southern Europe, it is not realistic to use local caught wild eels, as this might be contrary to the final management target of increasing local escapement of silver eels. So, the only way to develop this measure is to use imported glass eels stocked directly or to use on-grown farmed eel. Pedersen and Rasmussen (2015) showed that stocking tagged farmed eels (3 g) in Roskilde Fjord was more profitable compared with tagged farmed 9 g eels. So, probably there is an optimal stocking size between glass eels and 3 g eels, and this has to be studied further.

Acknowledgements

The project was funded by the Danish Rod and Net License Fund and the European Marine and Fisheries Fund. Capture, handling and tagging was done under permission and in accordance with national rules.

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