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Original Article

Yield per recruit from stocking two different sizes of eel (*Anguilla anguilla*) in the brackish Roskilde Fjord

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Stocking of young eel is widely practised, as a measure, to meet the management target of the EU eel recovery plan. The target of the recovery plan is to increase the escapement to 40% silver eel biomass, relative to pristine conditions. The scientific information to predict the outcome in silver eel biomass from stocking is limited and may depend on whether translocation of wild glass eel or yellow eel is used, or if the stocked eels used are yellow eel from aquaculture. We evaluated the yield from stocking two different sizes, 3 and 9 g eels from aquaculture. A professional fishery recaptured 12.7% of the 3 g and 9.4% of the 9 g eels, originally stocked. Growth rate and mortality rate were different for the two stocked sizes, favouring the small eels. Brutto yield per recruit (YPR) was 13 and 9.2 g and netto YPR was 9.8 and 0.31 g for 3 and 9 g eel, respectively. We conclude that there seems to be no advantage in using larger 9 g eels compared with small 3 g eels for stocking.

Keywords: *Anguilla*, growth, mortality, stocking, yield per recruit.

Introduction

Since the late 1970s, the recruitment of glass eels to the continent has declined. In Scandinavia, the decline started as early as in the 1950s (ICES, 2009) and the current recruitment of glass eels is estimated to be between 2 and 10% of that observed in the late 1970s (ICES, 2013). The International Council for the Exploration of the Sea (ICES) recommends that all anthropogenic impacts on production and escapement of eels should be reduced to as close to zero as possible until stock recovery is achieved. In 2007, the European Council adopted a framework regulation for the recovery of the stock of European eel (EC, 2007). This regulation establishes a framework for the protection and sustainable use of the stock of European eel, and each EU Member State has to establish eel management plans with the objective to increase escapement of silver eels in river basins to 40% of the pristine silver eel biomass. These actions that can be taken include reducing anthropogenic mortality (e.g. fishing and hydropower turbines), combatting predators (e.g. cormorants), improving river habitats, and stocking of young eel.

Since artificial reproduction of eel is not yet possible, the only source of eel for stocking is wild-caught glass eel or yellow eel. However, glass eel may be on grown in eel culture and stocked as yellow eel.

Stocking lakes, rivers, and brackish marine waters with glass eels or yellow eels has been done for decades in most countries throughout Europe. The scientific information for predicting the outcome in silver eel biomass from stocking is limited. Many studies are short-term studies dealing with the growth and recapture rates of yellow eel, e.g. Andersson *et al.* (1991); Bisgaard and Pedersen (1991); Pedersen (1998, 2009); Lin *et al.* (2007); Simon and Dörner (2013), and only a few studies cover most of the eels lifespan, e.g. Wickström *et al.* (1996) and Pedersen (2000). The size and stage of stocking material (glass eel vs. yellow eel) and origin of the stocking material (cultured eel vs. wild eel) and trophic status of the water body may all impact the yield from stocking a water body with eel. In this study, we look at the effect of fisheries catch relative to stocking size. Simon and Dörner (2013) compared glass eels (0.3 g) and farm-sourced yellow eels (5–8 g) stocked in lakes, and found that the glass eels performed better in terms of growth and survival compared with the larger farm-sourced yellow eels, suggesting that farming of eels has a negative impact on growth and mortality. According to Ursin (1967), natural mortality *M* decreases with increasing body mass and, therefore, we assume that stocking larger eels will result in a better survival and consequently a better yield. In this study, we assess and compare the yield of two different sizes: 3 and 9 g eel.

Material and methods

Stocking area

The study site, Roskilde Fjord (Figure 1), has a catchment area of 1200 km^2 and a water surface of 123 km^2. The fjord is shallow with mean and maximum depths of 3 and 32 m, respectively. It is shaped like a basin with low water depth at the outlet to the Kattegat Sea, which causes the fjord water to heat up quickly in spring, and the water temperature in the fjord is warmer compared with adjacent marine Kattegat. The salinity is between 12 and 18 ppt. The lower salinity (12 ppt) is found in the inner part of the fjord, due to freshwater supply from several streams, and 18 ppt where the fjord enters the Isefjord and Kattegat.

A professional and recreational fishery mostly targets wild eel, which is the only fish species of economic significance in the fjord. Anglers mostly catch sea trout (*Salmo trutta*) and a little, but an unknown number of eel. The professional eel fishers use poundnets and fykenets, and recreational fishers use fykenets and longlines. Landings of eel are only reported by the professional fishers on logbooks to The Danish Agrifish Agency (www.agrifish.dk). The fishery mortality rate on eel in Roskilde Fjord is high. Unpublished population data (DTU Aqua) suggest that fishery mortality F is >1. Around Roskilde Fjord, a colony of cormorants (*Phalacrocorax carbo*) is present. The colony contained between 447 and 852 nests in the period 2001–2006 (Eskildsen, 2006), and a predation pressure from cormorants is expected, but no data on this subject are present.

Stocking material and tagging

The eels used for stocking were glass eel imported from France, during (January–April) in 1998 and 1999, to a Danish eel farm. Here, they were grown further for ∼3–6 months in a heated culture. This farm is controlled by DTU-Vet and was found free of the swimbladder nematode *Anguillicola crassus* and the infectious haematopoietic necrosis virus (IHNV); infectious pancreatic necrosis virus (IPNV); and Viral haemorrhagic septicaemia virus (VHSV). Furthermore, DTU Aqua requires that the eels, used for stocking,

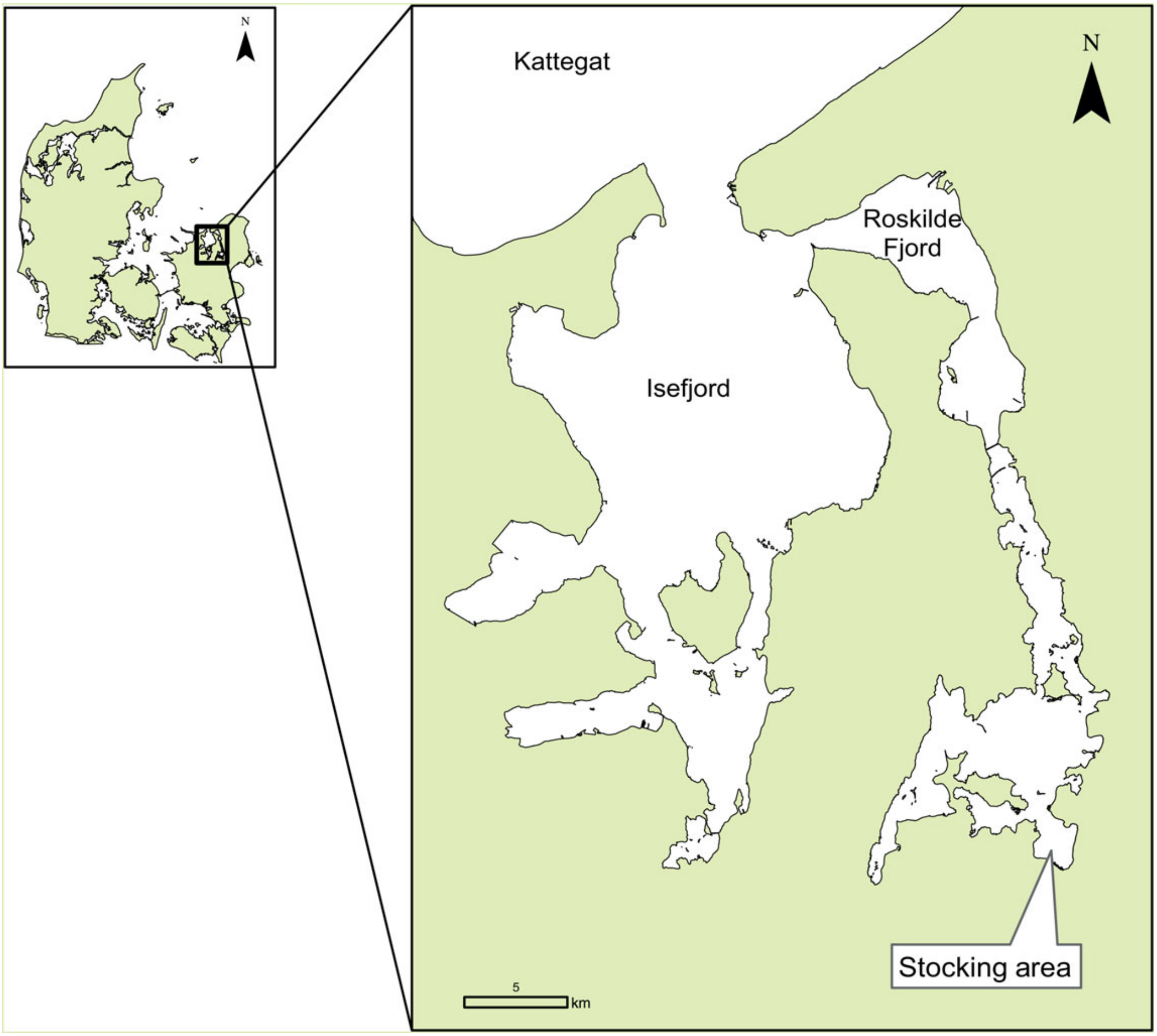

Figure 1. Map of Denmark and the study area Roskilde Fjord. This figure is available in black and white in print and in colour at *ICES Journal of Marine Science* online.

shall be captured as glass eels during the previous winter or spring and thus be maximum 8 months old when stocked.

In 1998 and 1999, two batches of small grown eel, ~3 g (SS) and large ~9 g eel (LS), were transported to the Danish Center for Wild Salmon (DCV) in Randers to be tagged. Here, they were acclimatized for 1–2 d, sedated with chlorobutanol (0.05% solution), and then tagged with standard size (1.1 × 0.25 mm) binary coded wire tag (CWT). The tag was injected through the skin in the dorsal musculature (Thomassen *et al.*, 2000), using an automatic tag injector (MKIV) (Northwest Marine Technology, Inc.). Tag retention was measured for all batches and years on a random sample ($N = 100$) of tagged eel before they were packed in polystyrene boxes and transported, by car, to Roskilde Fjord. At Roskilde Fjord, several recreational fishers were waiting ready with boats to scatter the eels on water depth of 1–3 m with vegetation (*Zostera maritima*) or soft bottom in a large area in the inner parts of Roskilde Fjord (Figure 1). Despite the transportation time of 5 h, the tagged eels were fresh and active and no mortality was observed at release. Stocking batches of SS and LS eels took place in late July and early September 1998, and early June and mid-July in 1999 (Table 1). A total of 50 603 eels: 3.0 and 3.4 g (SS) and 50 268 eels: 8.4 and 9.4 g (LS) were tagged. Initial CWT loss was measured to be between 0.5 and 1.7% in the different batches and tag loss increases only slightly with time (Thomassen *et al.*, 2000). The tag loss measured after the first week was used to calculate the number of fish with a tag released in the fjord (Table 1).

Sampling catches

Most fishers operating on the fjord landed their catch in a live storage facility named Jyllinge Eel Export and once a week, the catch was collected by a professional eel trader. When possible, we checked the catches for tags using a CWT tunnel detector (Northwest Marine Technology). In this facility, the eels were already graded by discarding eels below the minimum legal size of 35.5 cm

Laboratory work

CWT-recaptured eels were brought to the laboratory and frozen down. During the following winter, defrosted eels were measured in length and weight, and the sex was determined macroscopically according to Sinha and Jones (1975). Defrosted eels were corrected to length and weight according to the formulas given by Simon (2013) and were separated into yellow and silver eels. The eels denoted as silver eels were in an early migration stage such as stage IV according to Durif *et al.* (2005). The CW-tag was removed from the eel and the binary batch code identified using a microscope. In this way, all eels could be distributed on the year of stocking and size groups SS and LS.

Data treatment and calculations

The recaptures of the four stocked batches (Table 1) were reduced to two batches (SS and LS) by pooling both years of stocked small eels in one batch (SS) and both years of large stocked eels (LS) in another batch; so by pooling the two batches, the data for both batches SS and LS are mean values. Assuming the same total mortality Z after stocking in 1998 and 1999 for SS and LS, respectively, the data for SS and LS, respectively, were pooled by the year of catch. Total mortality $Z = M(\text{natural}) + F(\text{fishery}) + E(\text{migration})$ was calculated as the annual mean for each stocking size SS and LS. Fishery recapture, number of specimens, was calculated as $F_{\text{recap}} = C_i / C_{\text{exam}\ i} \times R_i$; where C_i is the commercial catch, C_{exam} is the examined catch, and R_i is the recapture of tagged eel in year i. Fisheries yield $= F_{\text{recap}} \times W_i$, where W_i is the average weight of recaptured eels in year i.

Yield-per-recruit (YPR) brutto was calculated as total fisheries yield from stockings divided by the numbers stocked (Beverton and Holt, 1957). In calculation of the yield, sex and stage were disregarded, since only the biomass is important for the results.

YPR netto was calculated as YPR brutto minus biomass of stocked eels. Production per recruit (PPR) was calculated as total mass increase after stocking of the caught eels divided by the number of stocked eels.

To cover the period 2007–2011 where no data were collated, extrapolation of total mortality and average weight of caught tagged eels was used to calculate the expected capture over the period 2007–2011.

The annual growth increment was calculated as follows: Increment $= (L_{\text{recap}} - L_{\text{stock}})/(T_{\text{recap}} - T_{\text{stock}})$, where L_{stock} is the mean length of the batch at release (Table 1) and L_{recap} is the pooled mean length at recapture in year T.

Statistical analyses were performed with the statistical program IBM SPSS statistics 21.0.

All capture, handling, and treatment of experimental fish were done according to local ethical and legal regulations, guidelines, and permission (2012-DY-2934-00007) from the Danish Experimental Animal Committee.

Results

Eel stage, size, and sex

Of all the eels recaptured in the commercial fishery during the study period, 49% ($N = 781$) were silver eels and 51% ($N = 805$) were yellow eels. Silver eels were captured from the third post stocking year. The mean length of the recaptured yellow eels (384 mm, SD 50, min–max, 320–595, $N = 805$) was significantly larger (Mann–Whitney; $p < 0.001$) than that of the recaptured silver eels (367 mm, SD 38, min–max, 310–615, $N = 781$). The recaptured silver eels were mostly males (93%), whereas the recaptured yellow eels were mostly females (57%; Table 2).

Mortality and growth

The breakpoints of the graphs in Figure 2 imply that the SS and LS eels are fully recruited to the fishery in the fourth and third post stocking year, respectively. From the fourth post stocking year, the SS eels are captured in greater number than the LS eels and the

Table 1. CW-tagged eel released in 1998 and 1999.

Date of release	Length (cm)	Weight (g)	Tag loss (%)	Number	Batch number
22 July 1998	12.6	3.4	1.2	25 040	No number
04 September 1998	18.1	9.4	1.7	24 590	23-04-2020
04 June 1999	12.9	3.0	1.5	24 8700	23-04-2021
17 July 1999	17.9	8.4	0.5	25 120	23-04-2022
Total				**99 620**	

Table 2. Sex distribution of recaptured fish, number, and percentages.

Stage	Male eel *N* (%)	Female eel *N* (%)	Unidentified sex *N* (%)	Total
Yellow	281 (35)	482 (61)	31 (4)	**794**
Silver	714 (92)	56 (7)	3 (<1)	**773**
Total	**995**	**538**	**34**	**1567**

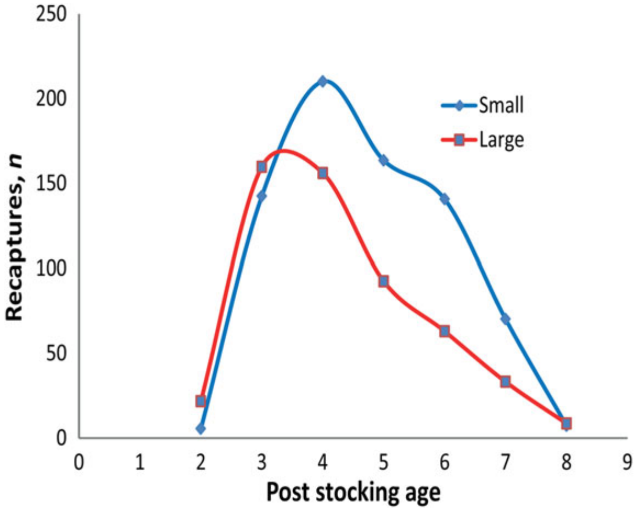

Figure 2. Number of small (SS) and large (LS) recaptures based on 1000 kg catch. This figure is available in black and white in print and in colour at *ICES Journal of Marine Science* online.

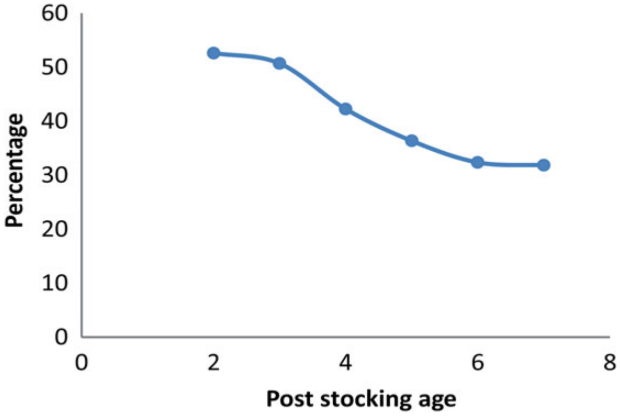

Figure 3. Proportion of large (LS) and small (SS), LS/ (LS + SS) in percentage with post stocking age. This figure is available in black and white in print and in colour at *ICES Journal of Marine Science* online.

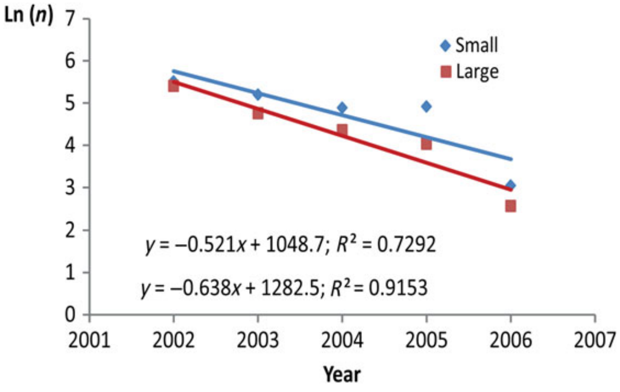

Figure 4. Total mortality Z (M + F + E) for small (SS) and large (LS) eel.

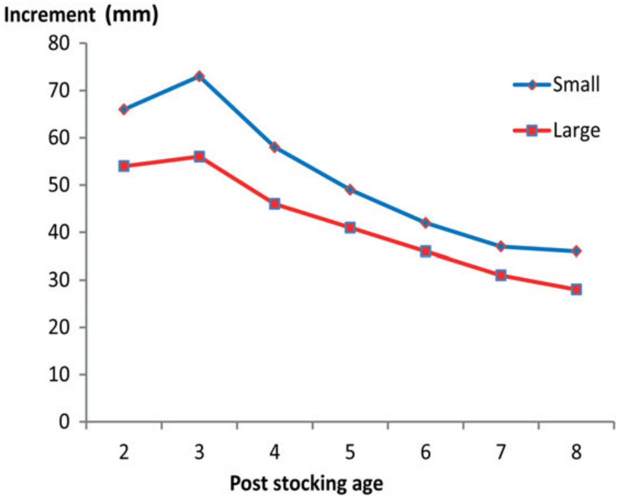

Figure 5. Mean length increment after stocking of small (SS) and large (LS) eel. This figure is available in black and white in print and in colour at *ICES Journal of Marine Science* online.

proportion of LS to SS eels decreases from an expected 50% down to ~30% (Figure 3). After the fish enter the fishery, the annual total mortality Z (Figure 4) is higher for LS than that of SS ($p \leq 0.081$). From 2002 to 2006, the total mortality Z (LS) = −0.64 and Z (SS) = −0.52. In total, 58% of the recaptures are SS eels and 42% are LS eels. Growth in mean annual length increment of SS (51.6 mm) and LS (44.3 mm; Figure 5) was significantly different (Mann–Whitney; $p < 0.001$).

Yield

The official catches reported by professional fishers at Roskilde Fjord during 2001–2006 were 47.6 ton; of these, 7.3 ton (15%) was examined for CW-tags. The total fisheries capture of the cohorts 2001–2011 was calculated to 12.8% of the SS and 9.4% of the LS eels (Tables 3 and 4). The YPR brutto was 13.0 g for SS eel and 9.2 g for LS eel. YPR netto was 9.8 and 0.31 g for SS and LS, respectively and total PPR was 12.5 and 8.4 g for SS and LS, respectively.

Discussion

Tagging

The use of CWT does not seem to affect the growth or mortality of eel significantly and tag loss is fairly low (Thomassen *et al.*, 2000; Simon and Dörner, 2011). In this study, tag loss was measured between 0.5 and 1.7% at the time of stocking (1 week after tagging). In a 4-week experiment, Thomassen *et al.* (2000) found that the main tag loss was observed to take place during the first week and only increased further 0.5% during the following 3 weeks. Simon and Dörner (2011) found, in their survey, tag loss to increase from 1.2% at day 32 to 3.7% at day 512. We assume that the incision hole made at tagging had healed within the first month and therefore no further tag loss occurred.

Table 3. Recaptures and YPR estimate of small (SS) stocked eel.

			Sampling data		Fisheries	
Year	Official commercial catch(kg)	Examined catch (kg)	Recaptures number	Mean weight (g)	Recaptures number	Yield (g)
2001	9331	184	4	60.5	203	12 271
2002	9844	928	229	90.6	2429	220 169
2003	7659	1231	223	93.4	1371	128 036
2004	5524	2216	293	106.6	730	77 882
2005	7663	1260	172	108.3	1046	113 320
2006	7613	1523	32	145.1	160	23 212
2007	10 339	0	0	149.9	241	36 081
2008	6193	0	0	163.9	86	14 034
2009	5149	0	0	177.9	42	7521
2010	5696	0	0	191.8	28	5330
2011	7467	0	0	205.8	22	4452
In total	**82 478**	**7342**	**953**		**6358**	**642 308**
Recaptures (%)					**12.7**	
YPR (g)						**13.0**

From 2001–2006 sampled in the fisheries. From 2007–2011 growth, mortality recaptures, and yield are calculated.

Table 4. Recaptures and YPR of large (LS) stocked eel.

			Sampling data		Fisheries	
Year	Official commercial catch(kg)	Examined catch(kg)	Recaptures number	Mean weight (g)	Recaptures number	Yield (g)
2001	9331	184	9	69.1	456	31 516
2002	9844	928	206	88.7	2185	193 837
2003	7659	1231	143	98.5	879	86 600
2004	5524	2216	173	116.4	431	50 210
2005	7663	1260	71	117.5	432	50 758
2006	7613	1523	20	141.8	100	14 176
2007	10 339	0	0	152.6	104	15 907
2008	6193	0	0	166.0	33	5476
2009	5149	0	0	179.4	14	2600
2010	5696	0	0	192.8	8	1633
2011	7467	0	0	206.2	6	1210
In total	**82 478**	**7342**	**622**		**4648**	**453 923**
Recaptures (%)					**9.4**	
YPR (g)						**9.2**

From 2001–2006 sampled in the fisheries. Recaptures and yield are calculated for 2007–2011 from the growth and mortality parameters.

Sex and stage

Sheltered marine areas, such as bays and fjords, in Denmark have relatively large densities of eels and up to 2009 when the EU eel regulation was enforced, exploitation in marine areas was significant. This is also the case in Roskilde Fjord, where a high exploitation rate is believed to be the cause that very few eels may succeed to grow to a size bigger than 40–50 cm, and this may also explain why female silver eels are few. A sex ratio of 56% for yellow females found in this study (Table 2) is within the range of 44–59%, which was found in the wild yellow female population in Roskilde Fjord (unpublished data, DTU Aqua).

Growth

The mean annual length increment was significantly different for SS eels (51.6 mm) compared with LS eels (44.3 mm). The time-lag of ~6 weeks between the time the SS eels and the LS eels were stocked in the fjord, indicating that the first growth season for SS eels was 10–20% longer than that for the LS eels and therefore has a greater length increment in the first year. Decreasing growth pattern with age and length (Figure 5) is well known from other studies, e.g. Rasmussen and Therkildsen (1979); Bisgaard and Pedersen (1991), and Lin *et al.* (2007), and may also explain why the LS eels grow less than the SS eels. Rasmussen and Therkildsen (1979) suggest that this pattern arise from fast growers leaving the population as silver eels, thereby the slow growers stay behind and shape the population growth curve, which for most exploited fish species can be fitted to a von Bertalanffy growth model (von Bertalanffy, 1951).

Simon *et al.* (2013) compared the growth of farm-reared eel with glass eel and concluded that farm-reared eel needed a longer time to change from artificial food to natural prey, as the glass eels showed an overall better growth. It is possible that the longer time the eel stays in aquaculture on artificial food, the more difficult it will be to change to a new foraging strategy, so the SS eel may adapt faster to natural prey conditions than the LS eels.

Mortality

Roskilde Fjord offers an excellent growth habitat consisting of shallow warm water areas in contrast to the wave-exposed open coast in the Kattegat, but the stocked eels may find also excellent growth areas for eel in the adjoining freshwater systems and the adjoining Isefjord. After entering the fishery, the annual total mortality Z was higher for LS than for SS (Figure 4). This difference in mortality $E = -0.12$ (LS, $Z = -0.64$ and Z, SS $= -0.52$) may be caused by emigration away from the fjord. A possible emigration of SS eels cannot be calculated from the present data, so $E = -0.12$ is probably a minimum migration "mortality". The relation of LS : SS is about 1 : 1 (Figure 3) up to 3 years after stocking as expected from equal numbers of stocked eels but gradually hereafter stocking decreases to about 3 : 7. This is revealed in total mortality Z of LS, which is larger than for SS; natural and fishery mortality is probably the same, so the most likely explanation could be that LS eels to a higher degree migrate out of Roskilde Fjord to Isefjord and Kattegat or the adjoining freshwater systems. It may be hypothesized that the migration pattern after stocking depends on size at stocking, and that LS eels continuously migrate away from the area in a larger proportion compared with SS eels. So, the higher recapture in the fjord of SS eels (58%) compared with LS eels (42%) may be explained by differences in migration between the two sizes out of the fjord.

Another mortality factor is the colony of cormorants on Roskilde Fjord. The actual impact has never been investigated and is unknown. It may be speculated that cormorants have eaten more LS than SS during the first post release years due to the larger size of LS. The influence of cormorants on the survival of a stocked cohort of eel was studied by Jepsen *et al.* (2010), who released 5000 CW-tagged farmed eels of mean size of 14.4 g and 5000 of mean size of 28.6 g and modelled the consumption of eels. From CW-tags found in cormorant pellets, collected over a 3-year period, it was calculated that 44% of the stocked eels were consumed by the cormorants.

Yield

The YPR brutto to the professional fishery was 9.2 and 13.0 g for LS and SS stocked eels, respectively. The recreational fishers constitute a rather large group of fishers on Roskilde Fjord. The effort of recreational fishers was estimated equal to 25% relative to the professional fishery (Pedersen, 2010). This suggests that total YPR brutto (i.e. commercial and recreational) was 11.5 and 16.3 g per recruit for LS and SS, respectively. Including fishery mortality outside Roskilde Fjord for LS gives additional YPR of ~4 g, so that YPR brutto for LS is ~15.5 g.

The YPR netto in Roskilde Fjord from the stockings to the professional fishery was 9.8 and 0.31 g for SS and LS stocked eel, respectively. From fisheries economic point of view, YPR netto takes into account the profitability of the fish caught in relation to the value/weight of the released fish and is therefore necessary when assessing the outcome of any release. One of the reasons for the difference in YPR netto between LS and SS is of course that after release the SS eels grow without any cost in the fjord up to the larger size of the LS eels when these are stocked. Another reason is the probable increased emigration rate of LS as described earlier.

The yield in this study was low compared with Lake Fardume Träsk (Wickström *et al.*, 1996). In the Lake Fardume Träsk, the recapture rate was 11% and YPR netto was 47.2 g using approximately the same stocking size (2.9 g) as the SS eels in this study. The major difference is not the recapture rate, but that individual eels captured in Lake Fardume Träsk had a mean weight of 420 g because of the catch of large female eels compared with a mean weight of 101 and 98 g for SS and LS, respectively, in this study. Moriarty and Dekker (1997) summarized YPR brutto and found a general figure of 40–50 g recruit^{-1} with extremes from 5 to 105 g in warm waters. Vøllestad and Johnsson (1988) found YPR brutto of 115.6 g in River Imsa, Norway. Pedersen (2000) stocked cultured eels (39.2 g) and wild eels (19.2 g) in a newly established lake (6 ha) and 7 years post stocking YPR brutto was in the range of 76–117 g for cultured eel and 189–263 g for wild eel. This high yield was due to a high survival of 42–57% (cultured) and 55–75% (wild eels) and mean weight 285 g (cultured) and 363 g (wild) at recapture.

If the legal size in Roskilde Fjord, with the present fishery mortality, was increased the eels would grow to a bigger size and the potential YPR would increase accordingly (Pedersen and Rasmussen, 2013).

The PPR (12.5 and 8.4 g for SS and LS, respectively) integrates the growth and survival of those eels caught during the period from stocking to catch and equals biological production (Chapman, 1967), and the figures for LS and SS eels, respectively, show that growth rate and mortality rate are different for the two stocked sizes, favouring the SS eels.

Despite the slight uncertainty of the true yield in this study, the same condition applies to both SS and LS eels, and we conclude that there seem to be no advantage using a larger 9-g eel for stocking as YPR was much higher for SS eel compared with large LS stocked eel.

Acknowledgements

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