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Survival and growth of European eels stocked as glass- and farm-sourced eels in five lakes in the first years after stocking

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Abstract – European eels *Anguilla anguilla* stocked as wild-sourced glass eels showed a better overall performance of growth and survival compared with farm-sourced eels after stocking in five isolated lakes within a 7-year study period. Eels stocked as farm eels lost their initial size advantage over eels stocked as glass eels within 3–5 years after stocking. Population sizes estimated for consecutive stocking batches indicated that 8–17% of eels stocked as farm eels survived 3–6 years after stocking compared with 5–45% of eels stocked as glass eels. This study coupled with results of previous studies suggests that stocking of farm eels may have no advantage in growth and survival compared with stocking of glass eels if stocking occurs at an optimal time in spring. In addition, the use of relatively expensive farm eels may provide no general advantage over stocking of glass eels. However, if glass eels are only available for stocking purposes very early in the year, lower survival rates than obtained in the present study can be assumed and stocking with relatively more expensive farm eels could possibly be a better option.

Key words: *Anguilla anguilla*; glass eel; mark–recapture experiment; stock assessment; marking; stocking

Introduction

The practice of stocking of European eel *Anguilla anguilla* (L.) for fisheries, both commercial and recreational, has been conducted in Europe for more than 100 years (Walter 1910; Wickström 1984). It has recently become more common with the aim to stabilise stocks because of low stock sizes and a substantially reduced natural immigration of elvers in recent years (Knights 2003). In general, glass eel recruitment did show a distinct decline starting in the early 1980s and recruitment estimates dropped to 1–9% of the 1970s levels (ICES 2010). To halt the dramatic decline in eel stocks, various management initiatives have been initiated. In 2007, the European eel was listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) to control international trade and the EU Council adopted a regulation (EU 2007) establishing recovery measures for European eel stocks. Stocking eels in freshwater bodies connected to the sea is one possible measure to fulfil the requirements of the regulation, which aims to ensure that 60% of the eels <120 mm total length (L_T) caught annually should be reserved for stocking. The deadline for achievement has been set for the end of July 2013, and many EU Member States aspire to use eel stocking as a part of their national management plans (ICES 2009). Currently, eleven European countries are known to buy eels (yellow and glass eels) for stocking purposes (ICES 2009).

Stocking with glass eels became common around 1900 in Germany (Walter 1910; Lübbert 1923) and later in other countries in Europe (Moriarty & McCarthy 1982; Wickström 1984) because of the barriers to immigration in rivers. An alternative to stocking with glass eels was the catch of elvers in estuaries of rivers with high natural immigration for stocking in tributaries and lakes with low or no natural immigration (Walter 1910; Müller 1975;

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Wickström 1984). As a result of the dramatically decreased natural immigration of glass eels to the European coast and the increasing demand for European glass eels by China (ICES 2009), the glass eel price has steadily increased since the 1960s (ICES 2008; Crook 2010). Consequently, rearing of glass eels in eel farms (to so-called ongrown farm eels of 5–8 g) before stocking seemed to be economically more profitable. It was assumed that the survival of glass eels grown-on in a farm to a particular size was higher compared with glass eels in the wild. Additionally, the stocking of farm eels should allow for a better planning of stocking activities (availability several months prior to stocking is given) and for stocking at favourable conditions when water temperature and natural prey availability are sufficiently high. Furthermore, it was assumed that farm-sourced eels show a growth advantage over glass eels and thus reaches a suitable size for re-catching earlier. It was also expected that the survival rate of the larger farm eels would be much higher than that of glass eels; however, these assumptions and expectations have not yet been proven (ICES 2008).

The growth of stocked glass eels, elvers and farm eels has been investigated in previous studies (Wickström 1986; Klein-Breteler et al. 1990; Andersson et al. 1991; Bisgaard & Pedersen 1991; Pedersen 1998, 2000, 2009; Lin et al. 2007; Kruitwagen & Klinge 2012; Simon et al. 2013). Annual length increments under different environmental factors, age and size class were estimated for naturally recruited elvers as 38–91 mm, stocked elvers as 51–83 mm and stocked farm eels as 25–65 mm (Bisgaard & Pedersen 1991; Pedersen 1998; Lin et al. 2007; Simon et al. 2013). Furthermore, the recapture of cultured eel was lower than of wild eel in a river and a lake 1 and 7 years after stocking (Bisgaard & Pedersen 1991; Pedersen 2000). No comparison of the survival between European glass and farm eels jointly stocked in lakes, however, has been conducted until now. Therefore, the aim of the present study was to examine growth and survival of glass and farm eels jointly stocked in five lakes over a period of 7 years.

Study area

For the stocking experiment, five isolated lakes without access to natural recruitment and of <20 ha in size were chosen. These eutrophic lakes (Table 1) are situated in the Federal State of Brandenburg (Germany). The limnological parameters of the lakes were taken from the lake register of the Federal State of Brandenburg and from our own investigations during the fishing occasions (Table 1). The lakes Großer See and Schloßsee have been stocked with farm eels and elvers (immigrating yellow eels) continuously since 1993. The remaining three lakes have been sporadically stocked with farm eels until 2001.

Materials and methods

For stocking, wild glass eels from England were obtained through a commercial eel trade company and stocked in April. Farm eels (grown from glass eels from France) were obtained from German commercial eel farms and stocked in May–June. Net prices (mean over the years 2004 to 2007) were €675 per kg for glass eels and €47 per kg for farm eels. Mean $\pm$ SD weight (W) (in g) for stocked eels was 0.27 ± 0.004 g for glass eels and 6.6 ± 0.34 g for farm eels (Table 2) resulting in an average price of €0.18 per glass eel and €0.31 per farm eel, respectively. Lake Görnsee was stocked with both glass eels and farm eels in 2004 and 2006. Lake Godnasee was stocked with glass eels in 2004 and with farm eels in 2005 and with both glass eels and farm eels in 2006. Lakes Großer See, Rähdensee and Schloßsee were stocked with both glass eels and farm eels in 2005 and 2007. All lakes were stocked with approximately 200 glass eels ha^{-1} and 55 farm eels ha^{-1}.

Table 1. Characteristics of the five lakes in the Federal State of Brandenburg, year of last stocking with eels prior to the study period and eel density in the lakes as estimated by electro-fishing.

Parameter	Godnasee	Görnsee	Großer See	Rähdensee	Schloßsee
Longitude	13°58′W	12°39′W	14°00′W	14°27′W	14°00′W
Latitude	52°08′N	52°21′N	52°42′N	52°04′N	52°42′N
Fishing area (ha)	18.36	16.22	16.50	10.00	13.15
Maximum depth (m)	6.5	3.1	8.5	7.0	7.5
Average depth (m)	5.5	2.5	6.5	5.0	5.0
Stratified	Yes	No	Yes	Yes	Yes
Total phosphorus concentration (TP) (μg l^{-1})	44	43	93	35	95
Secchi disc depth in May (m)	1.6	1.1	2.0	2.9	1.2
Trophic status	Eutrophic 1/Eutrophic 2	Eutrophic 1/Eutrophic 2	Eutrophic 2	Eutrophic 1/Eutrophic 2	Eutrophic 2
Year of the last stocking with eels	1997	2001	2004	2001	2004
Eel density (stk. 100 m^{-1})	0.3	7.8	6.9	11.1	21.5

Table 2. Mean ± SD total length (L_T) (mm) and weight (W) (g) at stocking for eels stocked in the five lakes in the Federal State of Brandenburg.

	Glass eels		Farm eels	
Years of stocking	L_T	W	L_T	W
2004	70 ± 3	0.24 ± 0.04	144 ± 36	4.8 ± 4.1
2005	74 ± 3	0.25 ± 0.04	159 ± 23	5.5 ± 3.2
2006	72 ± 4	0.31 ± 0.05	169 ± 18	6.8 ± 2.5
2007	73 ± 3	0.29 ± 0.04	187 ± 23	9.2 ± 3.8
Mean	72	0.27	165	6.6

Before stocking, glass eels were marked in a bath with alizarin red S (ARS) by the first stocking and with oxytetracycline hydrochloride (OTC) by the second stocking as described by Simon & Dörner (2005). During the tagging procedure, 100 individuals were sampled from each batch of glass eels to determine the initial total length (L_T) and weight (W) (Table 2) for calculating the total number of stocked eels. All farm eels were measured (L_T) and individually tagged with a decimal coded wire tag (CWT) (Northwest Marine Technology, Inc. [NMT], Shaw Island, WA, USA). The CWTs were injected into the dorsal musculature 1 cm behind the head as described by Simon & Dörner (2005) for the first stocking and into the musculature of the tail fin ca. 1 cm posterior to its origin for the second stocking. The different tagging locations make it easy to distinguish between both stocking batches without killing the fish after recapture. Prior to measuring and tagging with CWTs, the fish were anaesthetised with tricaine methanesulphonate (MS-222, 0.012% aqueous solution). Each fish was examined for successful tagging using a portable sampling Detector (V-Detector) (NMT). The three marking methods (OTC, ARS and CWT) are suitable for easy and fast mass-marking of glass and/or farm eels fulfilling the capture–recapture assumption of no marking–induced effect on growth and survival of marked fish as shown in detail by Simon et al. (2009) and Simon & Dörner (2011). Mark retention was reported up to 3 years in OTC-marked glass eels (Alcobendas et al. 1991), up to 2 years in ARS-marked glass eels (Simon et al. 2009) and was over 95% for CWT-marked farm eels after 16.5 months (Simon & Dörner 2011).

One year after first stocking, monitoring of the stocked eels commenced and was carried out every year until 2009. Each year in May, all lakes were sampled three times by electro-fishing (FEG 5000; Fa. EFKO, Leutkirchen, Germany; 8 kW, voltage series, 220–450 V direct current) from a boat along the entire shoreline. The size selectivity of this method against smaller fish cannot be completely excluded but was probably low, because of the experience of the fisherman and the high number of very small eels in the catch. The captured eels were anaesthetised with MS-222 (0.012% aqueous solution), and L_T (± 1 mm) and W (± 1 g) of each captured eel were recorded. Each fish was examined for CWT using a V-Detector (NMT). Eels not marked with CWTs and in a size range up to +150 mm of the largest stocked glass eel or recaptured stocked eel of the previous year were killed with MS-222 (0.015% aqueous solution). If the number of recaptured eels not marked with CWTs was below 25 per lake and in each fishing event, all recaptured eels were killed. If the number of recaptured eels exceeded 25, a random subsample over the total size distribution was taken (Table 3). All other eels were released after complete recovery from anaesthetising. Dead eels were individually marked with a number on a small piece of waterproof paper in the mouth and stored at −20 °C. The L_T and W after capture were assigned from the capture protocol by means of the individual marks.

From end of April to end of June 2010, a mark–recapture experiment was also carried out to investigate population sizes of the consecutive stocking batches. The lakes were fished six to ten times, and at each sampling occasion, the entire shoreline was fished by electro-fishing (FEG 5000) from a boat. All eels in a size range up to +150 mm of the largest recaptured stocked eel of the previous year were anaesthetised with MS-222 (0.012% aqueous solution) at the end of the fishing event. Each sampled fish L_T (± 1 mm) and the associated W (± 1 g) were measured. Individuals were examined for CWT using a V-Detector (NMT), the CWT-tagging location was noted, and the eels were marked with a visible implant elastomer tag (VIE). The VIE mark was placed along the base of the ventral tail fin margin ca. 1 cm posterior to its origin as described by Simon & Dörner (2011). This marking method is suitable for easy and fast marking of small eels, fulfils the capture–recapture assumption of no marking–induced effect on growth and survival of marked fish, and mark retention is suitable for short-term mark–recapture experiments (Simon & Dörner 2011). Finally, after complete recovery, all eels were released over the entire shoreline of the lake. At the following fishing events, eels were checked for VIE marks and all unmarked eels were marked, as described above, prior to release. At the two last fishing events, a sub-sample of eels not marked with CWTs was killed and stored for further investigations, as described above, to determine the size distribution of each stocking batch (Table 3).

Sagittal otoliths of eels not marked with CWTs were extracted, cleaned and stored in 96% ethanol. One otolith per individual was embedded with the convex side up in transparent wax (Mounting Wax Crystalbond 509; Fa. Buehler GmbH, Düsseldorf,

Table 3. Number of stocked farm eels recaptured and stocked glass eels recaptured and killed for further investigations in the laboratory within the first years after stocking from the five lakes in the Federal State of Brandenburg. Note: In 2010 (the last entry in each column), eels were sampled at six to ten individual fishing occasions per lake, and higher sample sizes (approximately 50) were collected compared with previous years, where three separate samplings took place and approximately 25 eels per lake were collected.

		Godnasee		Görnsee		Großer See		Rähdensee		Schloßsee	
Stocking form	Years after stocking	1st stocking event	2st stocking event	1st stocking event	2st stocking event	1st stocking event	2st stocking event	1st stocking event	2st stocking event	1st stocking event	2st stocking event
Glass eels	1.	–	4	–	3	10	12	9	10	5	1
	2.	8	8	12	13	32	19	24	24	14	25
	3.	24	7	36	21	27	53	20	45	10	18
	4.	18	35	42	29	18		22		25	
	5.	44		18		26		41		16	
	6.			43							
Farm eels	1.	–	6	–	11	12	37	6	38	6	5
	2.	1	2	13	3	20	27	8	26	4	11
	3.	4	8	2	11	10	56	4	60	2	13
	4.	9	38	6	19	12		15		6	
	5.	22		1		14		13		1	
	6.	34		6							

Germany) on a microscope slide and ground with a series of grinding papers (600, 800 and 1200 grade) down to the centre. Finally, the otolith was observed under a UV-light microscope (Fa. Ernst Leitz Wetzlar GmbH, Wetzlar, Germany) equipped with two epifluorescence filters, one of 515–560-nm wavelength and one of 355–425-nm wavelength at 125-fold magnification to identify ARS or OTC marks. In all cases, marks were clearly identifiable as mark. Eels showing no ARS or OTC marks on the otoliths were excluded from the sample as not belonging to the stocked population. Only individuals identified as originally stocked eels were included in the analysis (Table 3).

Data analyses

For population size estimation in 2010, stocking batches and resident eels in each lake were identified with the help of subsamples investigated in the laboratory and by length frequency analyses of the capture protocols with the Bhattacharya method (Bhattacharya 1967), using FiSAT II (Gayanilo et al. 1995). Population size of stocked eel batches was estimated with Bailey's (1951, 1952) modification of the Lincoln–Petersen estimation by the last fishing occasions and with the Schnabel (1938) estimator as described by Krebs (1999). Estimates with one or no recaptured marked eel and for which the coefficient of variation was larger than 0.5 were excluded because such estimates have a too low precision. To estimate the percentage of eels surviving from each stocking batch, the population size of eels estimated in 2010 was set in relationship to the number of eels stocked initially.

Statistical analyses were performed with SPSS 9.0. (SPSS Inc., Chicago, IL, USA). Because the assumptions of normality and homogeneity of variance were not met, nonparametric Mann-Whitney-tests (*U*-test) were used to test for significant differences between mean L_T of the recaptured eels stocked as glass eels or farm eels at stocking and in each year of recapture in each lake. The minimum sample size was set at six, and the significance level was taken as $P < 0.05$.

Results

Recaptures of eels stocked as glass and farm eels varied between zero and 60 eels per year and for each lake (Table 3). The number of recaptured eels stocked as glass eels increased with time and length over the study period (Table 3). In contrast, the number of recaptured eels stocked as farm eels slightly decreased over the study period.

The mean L_T of glass eels from the first stocking batch increased continuously and ranged from 186 to

311 mm 5 and 6 years after stocking in all lakes (Fig. 1). In contrast, the farm eels showed uneven growth. In some lakes (e.g., Lake Rähdensee, Lake Schloßsee), the mean increase in L_T was zero or negligible in the first year. In contrast, farm eels increased their mean L_T continuously in other lakes (e.g., Lake Godnasee and Großer See). After 5 and 6 years of stocking, the mean L_T of farm eels from the first stocking batch ranged from 179 to 347 mm (Fig. 1). Mean L_T of glass and farm eels differed significantly in all lakes at stocking time (Table 2, *U*-test, d.f. 1, $P < 0.001$). Three years after stocking, however, mean L_T of eels of the first stocking batch did not differ significantly between the two stocking groups in three of the lakes (Fig. 1, *U*-test, d.f. 1, $P > 0.05$). Five and six years after stocking, mean L_T of eels of the first stocking batch did not differ significantly between the two stocking groups in four of the lakes (Fig. 1, *U*-test, d.f. 1, $P > 0.05$). Eels of the second stocking batch showed the same decreasing difference in mean L_T with increasing age. Three years after stocking, however, mean L_T of eels differed significantly between the two stocking groups in all lakes (Fig. 1, *U*-test, d.f. 1, $P < 0.05$). This was in contrast to the eels of the first stocking batch, which had a lower mean length at stocking time compared with stocked farm eels of the second stocking batch (Table 2).

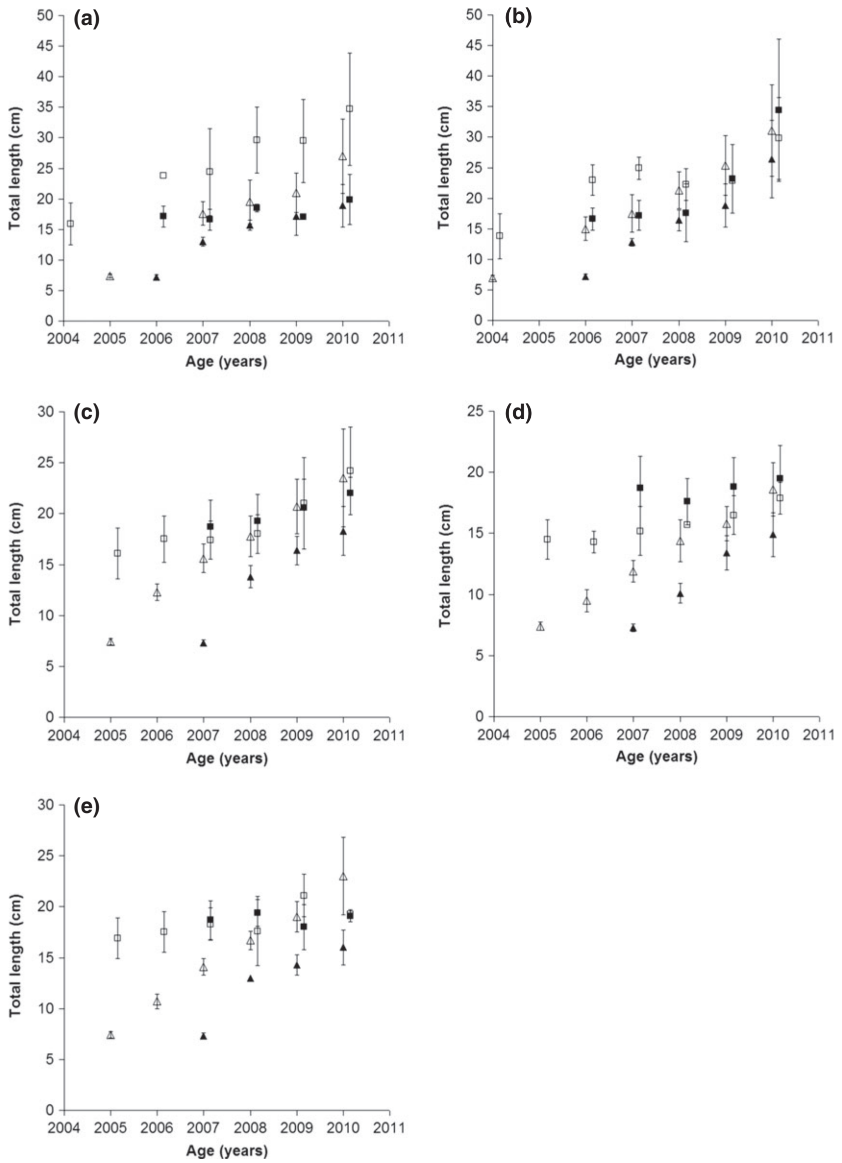

Fig. 1. Mean ± SD total length (L_T) of *Anguilla anguilla* (△ first, ▲ second, stocked as glass eels and □ first, ■ second, stocked as farm eels) in (a), Lake Godnasee; (b), Lake Görnsee; (c), Lake Großer See; (d), Lake Rähdensee; and (e), Lake Schloßsee in the first years after stocking. Note that in each year, measurements were taken at identical dates; the *y*-axis scale between lakes differs, and in some lakes for some years, only one or two eels were recaptured.

Table 4. Number of stocked eels recaptured (recapture rate 1) and marked with a visible implant elastomer tag (VIE), recaptured with a VIE mark by the last fishing occasions and recapture rates (recapture rate 2) by the mark–recapture experiment in the five lakes in the Federal State of Brandenburg in 2010.

Stocking form	Lake	Stocking event	Number marked with VIE	Recapture rate 1 (%)	Number recaptured with VIE	Recapture rate 2 (%)
Glass eels	Godnasee	1st	109	3	10	9
		2st	134	2	2	1
	Görnsee	1st	123	2	4	3
		2st	62	1	2	3
	Großer See	1st	55	2	3	5
		2st	199	5	16	8
	Rähdensee	1st	298	15	8	3
		2st	333	12	23	7
	Schloßsee	1st	40	2	2	5
		2st	57	2	1	2
Farm eels	Godnasee	1st	21	4	2	10
		2st	22	2	2	9
	Görnsee	1st	4	0	0	0
		2st	15	1	0	0
	Großer See	1st	9	1	0	0
		2st	42	4	2	5
	Rähdensee	1st	12	2	1	8
		2st	40	5	3	8
	Schloßsee	1st	2	0	0	0
		2st	9	1	0	0

The number of eels stocked as glass and farm eels and recaptured and marked with a VIE mark varied between 40–333 and 2–42 eels per lake and stocking batch, respectively (Table 4). Recapture of VIE marked eels by the last fishing occasion varied between 1 and 23 glass eels and zero to three farm eels per lake and stocking batch (Table 4). Estimated population size of stocked glass eel batches calculated after Bailey's (1951, 1952) modification of the Lincoln–Petersen estimation and with the Schnabel (1938) estimator was comparable in three of the five lakes (Table 5). The percentage of eels surviving showed high variation between lakes ranging from 5 to 45% for glass eels and 8 to 17% for farm eels 3–6 years after stocking (Table 6).

Table 5. Estimated population size of stocked eels with sufficient recapture rate by the mark–recapture experiment in the lakes in 2010.

Stocking form	Lake	Stocking event	Population size	SD	CV	95% CI
Glass eels	Godnasee	1st	486	123	0.254	242
		2st	2233	1083	0.485	2122
	Görnsee	1st	664	245	0.369	480
		2st	393	180	0.459	353
	Großer See	1st	399	166	0.415	325
		2st	1311	285	0.217	558
	Rähdensee	1st	596	133	0.224	261
		2st	1249	214	0.171	419
	Schloßsee	1st	120	49	0.408	96
Farm eels	Godnasee	1st	51	22	0.426	43
		2st	103	46	0.443	89
	Großer See	2st	155	69	0.447	136
	Rähdensee	2st	120	44	0.365	86

Discussion

The increase in L_T of eels varied within and between lakes, as reported in other studies (e.g., Moriarty 1987; Vøllestad 1992) and between stocking material (farm and glass eels) within one lake (Fig. 1). Similar mean lengths of stocked glass eels were reported by Andersson et al. (1991) with lengths ranging between 310 and 357 mm in a cooling water effluent area at the Baltic coast 3 years after stocking. Zero or negligible growth of stocked farm eels as observed in this study was also observed by Pedersen (2009). While noting that the glass eels in the farm originated from a different source to those stocked direct into the wild, the results show that the growth of stocked glass eels during the study period was generally faster than that of farm eels. In four of the five lakes, the glass eels reached a similar size as the farm eels after 3–5 years irrespective of their much smaller size at stocking time. Kruitwagen & Klinge (2012) also observed higher specific growth rates of glass eels compared with farm eels stocked in ponds within the first 6 months after stocking, and Pedersen (2000) observed a higher growth rate of stocked wild eels compared with farm eels in a lake. In contrast, a stocking study in a stream by Bisgaard & Pedersen (1991) revealed no difference in growth between stocked farm eels and stream-dwelling wild eels. In Lake Godnasee, farm eels were stocked 1 year prior to the glass eels. Thus, an advantage in growth and

Table 6. Comparison of estimated percentage of surviving individuals of stocked eels (glass eels, farm eels) with Bailey's (1951, 1952) modification of the Lincoln–Petersen estimation by the last fishing occasions and with the Schnabel (1938) estimator in the lakes in 2010.

			Bailey		Schnabel	
Stocking form	Lake	Age in 2010	Population size	Survival (%)	Population size	Survival (%)
Glass eels	Godnasee	5	486	16	509	16
		4	2233	41		
	Görnsee	6	664	8	730	9
		4	393	9	908	18
	Großer See	5	399	16	371	15
		3	1311	32	1201	30
	Rähdensee	5	596	32	660	35
		3	1249	45	1088	40
	Schloßsee	5	120	5	270	12
		3			1066	33
Farm eels	Godnasee	6	51	11		
		4	103	8		
	Großer See	3	155	17		
	Rähdensee	3	120	17		

survival of the farm eels in an environment without intraspecific food competition could be assumed. Despite this potential advantage for the stocked farm eels, the glass eels stocked 1 year later showed a higher increase in L_T and reached the body size of farm eels by the end of the study period (Fig. 1a). The lower growth of farm eels during the first years after stocking is in concordance with findings of Pedersen (2000) and Pedersen (2009). Decreasing gross energy values and fading interstitial fat reserves support the assumption that farm-sourced eels released into natural waters experienced malnutrition (Simon et al. 2013). Faster growth of glass eels during first years after stocking may also be attributed to smaller initial body size compared with farm-sourced eels.

The observed percentages of eels surviving 3–6 years after stocking were comparable with findings of De Leo & Gatto (1995). Pedersen (2000), however, observed after stocking with wild (19 g) and farm eels (40 g) clearly higher percentages of survived eels with 55–75% (wild eels) and 42–57% (farm eels) 7–8 years after stocking. In general, glass eels can be purchased from the U.K. or France from December to April but stocking too early would coincide with low water temperatures and very low natural prey availability. In the present study, glass eels of excellent quality were purchased and stocked at an optimal time in spring. This seemed to be an important precondition for the good growth and high survival rate observed. Due to low recapture rates (1–10%) during the mark–recapture experiment, the precision of estimates and power of conclusions drawn are limited. As eels reached a mean body length of 179–347 mm at the end of the study period, results are restricted to this size class. In addition, experiments were carried out in small lakes and may thus have limited explanatory value for large lakes or rivers. As said above, glass eels were stocked at an optimal time in April in the present study. This may not always be applicable as a standard approach. Availability of glass eels depends on factors such as the timing of their arrival at individual EU Member States' coasts, natural recruitment, catch quotas and national approaches towards glass eel fisheries. If stocking of glass eels is conducted earlier in the year, for example in January or February, when glass eels may become available but natural conditions are less favourable, lower survival rates than obtained in the present study can be assumed. Consequently, stocking with more expensive farm eels could be an alternative option especially for large stocking programs as it would provide for a better planning of stocking activities and for stocking during favourable conditions.

The observed differences in growth and survival of eels stocked as glass and farm eels can possibly be attributed to a variety of factors such as the quality of the original glass eels, food adaptation problems of farm eels after stocking and size grading of farm eels in the fish farms prior selling and stocking. Farm eels may need adaptation time to use natural food (Simon et al. 2013) during which they consume less food and fewer prey types compared with wild fish as described by other fish species (Sosiak et al. 1979; Ersbak & Haase 1983; Sundström & Johnsson 2001). Furthermore, it cannot be excluded that non- or slow-growing eels were sorted out in the eel farms after size grading and subsequently sold as stocking material. The prime economic interest of the farm companies focuses on the production of fast-growing eels for human consumption. Thus, the selling of non- or slow-growing eels for stocking purposes may be an additional source of income but it may potentially impact on the quality of the stocking material. Various studies on other fish species indicated that hatchery-reared fish showed substantial weight loss, declined condition, lower growth and up to 10 times higher mortality rates compared with wild fish after stocking (Miller 1954; Sosiak et al. 1979; Ersbak & Haase 1983; Sundström & Johnsson 2001; Sundström et al. 2004; Baer 2009). In addition, it can be assumed that per capita costs for buying farm eels should generally be substantially higher than for glass eels even if market for prices for glass eels may vary between years and countries of first sell.

The success of mark–recapture experiments depends on the number of fish marked and on the number of marked fish recaptured and examined (Robson & Regier 1964; Heimbuch et al. 1990). In the present study, the number of recaptured eels stocked as glass eels increased with time, resulting in a sufficient number for further investigations in four of the lakes with ≥ 10 eels per lake 3–6 years after stocking (Table 3). In contrast, the number of recaptured eels stocked as farm eels was relatively constant, and sample sizes for further investigations were low with mostly <10 eels per lake and year within the first 3 years after stocking. Farm eels were stocked at approximately four times lower density compared with the stocked glass eels. Despite the different stocking intensities, higher recapture rates (1–15%) of glass eels and lower recapture rates (0–5%) of farm eels were also observed during the VIE mark–recapture experiment.

Low sample size reduces the precision of the estimates, and the power of hypothesis tests can be unacceptably low (Heimbuch et al. 1990). Low recapture rates of marked fish after release, however, are a general problem of mark–recapture studies in the field. Naismith & Knights (1990) observed, in a mark–recapture experiment with eels (230–720 mm in size) in a small pond, recapture rates by electro-fishing of between 20 and 30%. Furthermore, recapturing stocked glass eels by electro-fishing is difficult because of the small size of the fish in the first years after stocking. Generally, the electro-fishing recapture rate of eels increases with increasing body length (Naismith & Knights 1990; Lambert et al. 1994), as also shown in the present study for glass eels. In contrast, the recapture rates of farm eels did not increase with time, probably as a result of the low increase in body size after stocking.

The present study demonstrated that stocked farm eels have no general advantage in survival and growth compared with glass eels after 3–5 years in small lakes when stocked at an optimal time in spring. Taking additional losses during the farm period into account, overall mortality should be lower when using glass eels for stocking purposes. In addition, due to usually higher prices per capita for farm eels, stocking of glass eels may also be economically advantageous. However, if glass eels would only be available for stocking purposes very early in the year, lower survival rates than obtained in the present study can be assumed and stocking with relatively more expensive farm eels could thus be a better option.

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