American Fisheries Society Symposium 58:149–156, 2009

Does Stocking of Danish Lowland Streams with Elvers Increase European Eel Populations?

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Abstract.—To counteract low elver recruitment to the Danish coast, a stocking program has been under development since the late 1980s. Glass eels imported from southern Europe are cultured to 2–5 g and stocked throughout the country in fresh and brackish water. To assess the value of these stockings, selected streams were stocked with eels weighing 3 and 9 g. Poststock evaluations by electrofishing were done 3–63 d after stocking in one system and up to four years later in another system. Instantaneous daily disappearance rate, including emigration and natural mortality, was high (D = 0.006–0.153) in both river systems. The reasons may include low water temperatures combined with a habitat offering too little shelter for the stocked eels.

Introduction

The Danish eel fishery has been decreasing continuously since the 1960s as a result of decreasing recruitment of young eels to the Baltic Sea beginning in the 1940s (Hagström and Wickström 1990). A notable decrease throughout the distribution area has been observed since the end of the 1970s (Dekker 2002).

A stocking program was initiated in 1987 with the purpose of increasing fish yield. Glass eels used for stocking were imported from southern Europe, cultured in commercial eel farms in Denmark, and stocked throughout Danish waters by recreational fishermen. Most fresh- and brackish-water habitats are considered suitable for stocking eels. Streams, in particular, are important growth areas (Rasmussen and Therkildsen 1979), and the natural capacity of streams to produce eels is considered to be underutilized.

Studies concerning stocking methods and population dynamics of stocked eels in running water have been conducted (Bisgaard and Pedersen 1991; Berg and Jørgensen 1994). These studies ran for 12 and 3 months, respectively, but did not evaluate the long-term effects of stocking. The present study was undertaken in two different river systems, carried out over two months and four years. The objective was to assess eel stocking in small streams, considering dispersion, disappearance, mortality, emigration, and growth.

Methods

Study Sites

Eels were stocked in two river systems. Madum Å is a small lowland stream (56°15’N, 8°20’E) with a total length of 25.6 km and a catchment area of 90 km^2. The stream flow

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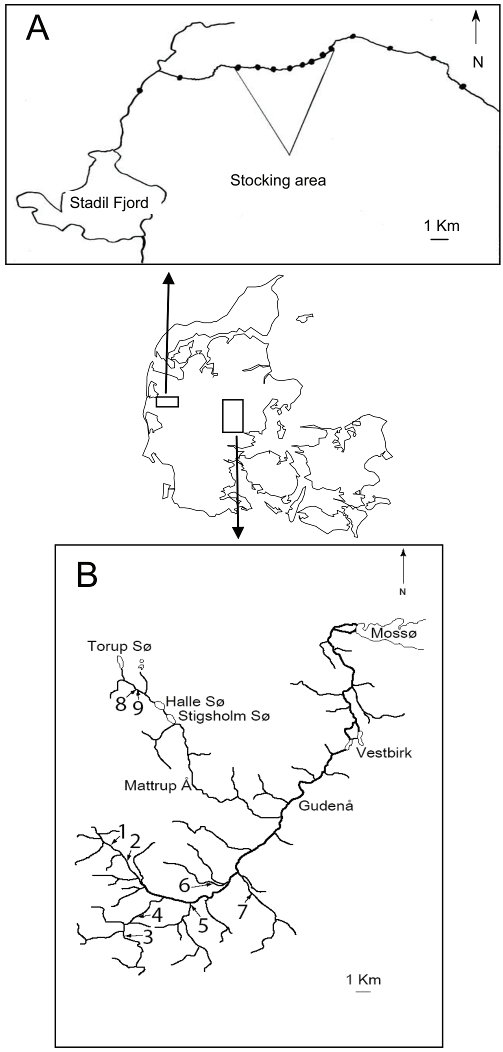

Figure 1. Location of study areas in Denmark indicated by rectangular inserts. A) Map of River Madum Å. • Single sites of 50-m sections electrofished. B) Map of upper part of River Gudenå. Numbers denote experimental sites.

into the brackish Stadil Fjord through extensively farmed agricultural land (Figure 1). Only the lower and upper parts of the stream are regulated by canalisation, and the water is moderately polluted by nutrients and ochre (Jakob Bisgaard, County of Ringkøbing, personal communication). Water depth in the study area varied between 0.2 and 0.7 m and river width between 2.5 and 5.9 m. In the years from 1992 to 1996 the stream was stocked annually in September with 13,000 elvers. Determined by electrofishing (Bohlin et al. 1989) these stockings and naturally emigrating eels produced a density of 0.09 eels × m^{-2} in 1999 .

The other river system was River Gudenå (55°52’N, 9°33’E), a large lowland stream 170 km long with a catchment area of 2,600 km^2. The river system is strongly influenced by human activities, including canalization, nutrient loading from agriculture, and hydroelectric power damming and development. Nine small tributaries in the upper part of the river with water depth 0.1–0.7 m and stream width from 1.5 to 4 m were selected as study areas.

The River Gudenå was stocked with 2.1 million elvers weighing 0.3–1.1 g in 1987, 1988 and 1992 (Berg and Jørgensen 1994). Therefore, in all the experimental streams in River Gudenå, a small population of eels was present (0.03 eels × m^{-2}).

Stocking and Tagging Procedures

Glass eels that were stocked were imported from France during the previous winter and cultured in heated water (25°C), at a commercial eel farm. At this temperature, glass eels reach a size of 3 g and 9 g after 3 and 6 months, respectively. From July 1998 to September 2001, five batches of 3-g eels and six batches of 9-g eels (Table 1) were batch-marked with coded wire tags (Thomassen et al. 2000). After 2–7 d of recovery, tag retention was routinely checked by a tunnel detector. Tag loss 2–7 d after tagging was 3% and 1% in the different batches of 3-g and 9-g eels, respectively.

Tag loss was recorded and the eels were transported in moist polyethylene boxes to the experimental streams.

In Madum Å, the 3-g eels were stocked in July 1998 and the large eels three months later, in September 1998; both sizes were stocked in the same stretch of the stream. The eels were scatter-stocked from a sailing canoe moving slowly downstream. The stocking area of the stream had a length of 5.475 m and stocking density for each size was calculated at 0.44 eels × m^{-2}.

In the tributaries of River Gudenå, tagged eels were stocked from July 2001 to September 2002. Workers wading in the stream scattered eels over 150–200 m stretches. Stocking densities were 1.5–3.6 eels × m^{-2} (Table 1).

Poststocking Assessments

Poststocking assessment was done by stream electrofishing (220 V, continuous DC). In Madum Å, 14 sections 50 m in length were electrofished from 1999 to 2002. Eight sections were inside the stocking area, two were downstream, and four were upstream. In the tributaries of River Gudenå, poststocking assessment was made between 3 and 63 d after stocking. Sections 25 m in length were electrofished at intervals of 50–100 m up and down the stream, beginning about 500 m downstream from the stocking area, and electrofishing was performed until no stocked eels were recorded in one or two sections.

Captured eels in each section were anesthetized, measured (0.5 cm), checked for tags by an R-8000 tunnel detector (Northwest Marine Technology, Inc.), and released in the same section.

Poststocking numbers of eels were estimated by using the removal method. Each section was electrofished two or three times in succession. The number of tagged eels in the stream was subsequently calculated according to Bohlin et al. (1989). In Madum Å, where both size groups were present in the same stretches of river, the 3-g and 9-g eels were separated by size, using 15 cm as the separation criterion.

Instantaneous disappearance rate (D) was calculated as $D = -\ln(N_1/N_o)/t$, where N_o is the number stocked, N_1 is poststock number; and t is the number of days between stocking and poststocking surveys.

Results

Poststocking Densities

In Madum Å, the first poststocking survey was done in May 1999, 234 d after the 9-g eels were stocked and 318 d after the 3-g eels were stocked. During that time, the number of stocked eels decreased by 85.5%. The

Table 1. Stocking and recapture data for coded wire tagged eels released in small tributaries to River Gudenå and River Madum Å. Length, weight, number stocked, and stocking density of tagged eels are given for each stream. Post-stocking assessment determined by electrofishing and number of recaptured eels are provided. Rate of disappearance, both daily and at 100 days, are given.

			Stocked eels				Post-stocking assessment		Disappearance rate	
Site	Stream width (m)	Stocking date	Length (cm ± SE)	Weight (g)	Number	Density (eels•m^{-2})	Days after stocking	No. tagged recaptured eels (mean ± 0.95 CI)	Instantaneous Daily100 days (mean ± 0.95 CL)	Actual %
Madum Å	2-6	July 1998	13.6 ± 1.2	3.4	6,500	0.44	318	830 ± 288	0.0065 ± 0.0009	48
Madum Å	2-6	Sep 1998	17.8 ± 1.9	9.5	6,500	0.44	234	1,056 ± 367	0.0078 ± 0.0013	54
Gudenå (1)	3.0	Sep 2001	18.5 ± 0.9	9.4	1,000	3.6	21	141 ± 72	0.0933 ± 0.0196	100
Gudenå (2)	4.0	Sep 2001	18.5 ± 0.9	9.4	2,040	1.9	24	455 ± 513	0.0625 ± 0.0315	100
Gudenå (3)	2.7	July 2001	12.6 ± 1.0	2.6	1,000	1.5	38	230 ± 128	0.0387 ± 0.0116	098
Gudenå (4)	3.9	Sep 2001	18.5 ± 0.9	9.4	1,068	1.6	3	675 ± 374	0.1529 ± 0.1470	100
Gudenå (5)	1.5	July 2001	13.0 ± 0.8	2.7	500	2.3	44	2 ± 3	0.1255 ± 0.0208	100
Gudenå (6)	1.8	Sep 2001	18.5 ± 0.9	9.4	500	2.3	10	108 ± 84	0.1532 ± 0.0575	100
Gudenå (7)	2.3	July 2001	13.0 ± 0.8	2.7	500	1.7	43	71 ± 144	0.0454 ± 0.0258	099
Gudenå (8)	2.5	July 2002	12.6 ± 1.1	2.8	1,053	2.0	63	71 ± 31	0.0428 ± 0.0058	099
Gudenå (9)	2.5	Sep 2002	18.5 ± 1.3	9.4	1,033	2.3	21	209 ± 82	0.0761 ± 0.0158	100

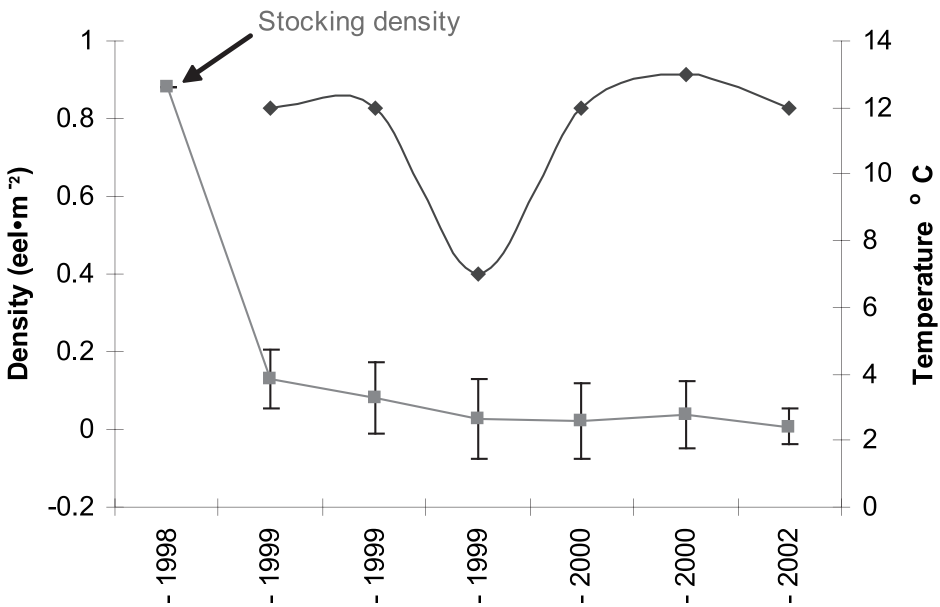

Figure 2. Temporal change in density of stocked elvers in River Madum Å, both size groups pooled, indicated by closed squares and 95% confidence limits. Water temperature indicated by closed diamonds.

decrease was of the same order of magnitude for both 3-g and 9-g eels (Table 1). Numbers have continued to decrease each year, and in May 2002 only 0.4% of the stocked fish were left in the study area (Figure 2).

In tributaries of River Gudenå, densities of stocked fish decreased quickly. Instantaneous disappearance rate on a daily basis ($D \times d^{-1}$) was between 0.039 and 0.153, suggesting that in six of the nine streams, the stocked fish disappeared within 100 d (Table 1).

Instantaneous Disappearance and Stocking Density

There was a weak linear relationship (linear regression, $P = 0.058$; $r^2 = 0.344$), between disappearance (D) and stocking density when eel size was not taken into consideration, suggesting that disappearance, emigration and mortality, or both increased with stocking density (Figure 3). However, when the analyses were separated by weight group, neither the 3-g nor the 9-g eels showed a significant relationship ($P = 0.098$; $r^2 = 0.654$ and $P = 0.389$; $r^2 = 0.189$, respectively), although the 3-g eels showed a slightly positive trend.

Migration

In Madum Å, stocked fish were found 1.0 and 3.5 km upstream from the stocking sites at densities of up to 0.08 eels $\times$ m^{-2} during the study period. No tagged eels were recorded in sections further upstream (5.0 and 7.5 km) and downstream (2.8 and 7.0 km).

In the tributaries of River Gudenå, the fish spread both upstream and downstream (Figure 4). The greatest downstream distance recorded was 250 m and the greatest upstream distance was 600 m.

Growth and Size Distribution

In tributaries of River Gudenå, poststocking length increment was not observed.

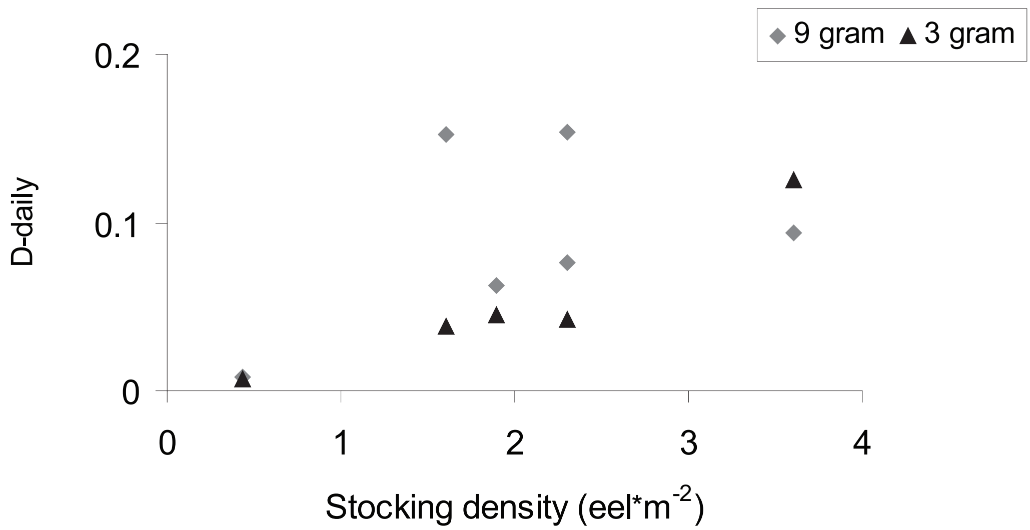

Figure 3. Instantaneous disappearance of stocked elvers from selected streams 1-4 m wide.

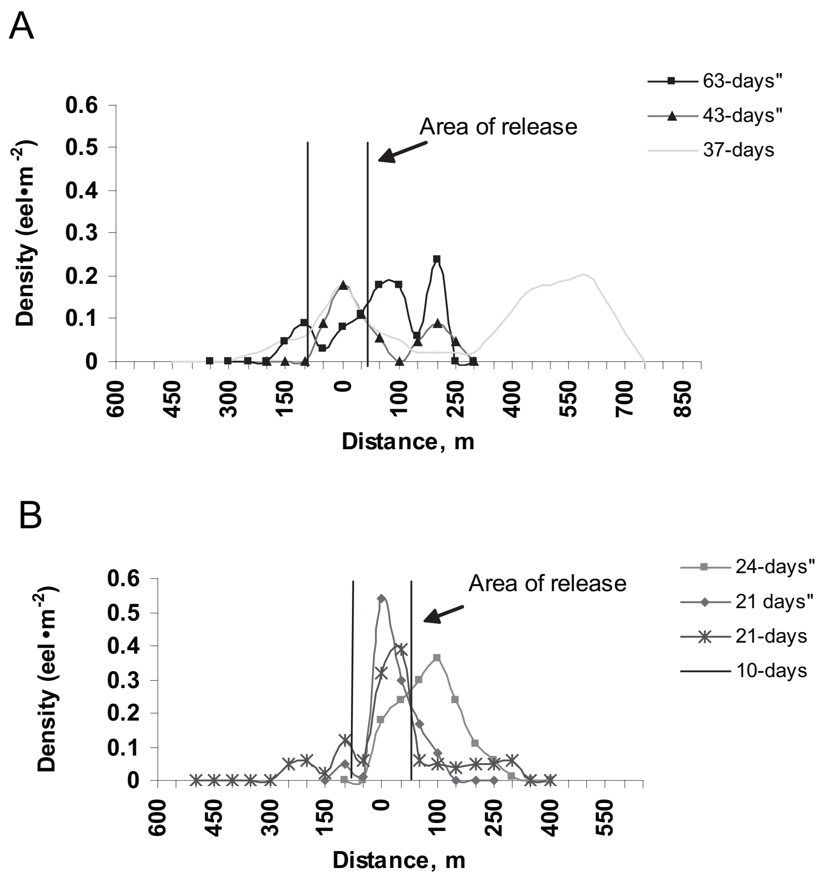

Figure 4. Dispersion of elvers stocked at two different sizes in tributaries of River Gudenå: (A) 3-g eels and (B) 9-g eels. Number of days at each site is the time between stocking and post-stocking survey. Direction of water flow is indicated by horizontal arrow.

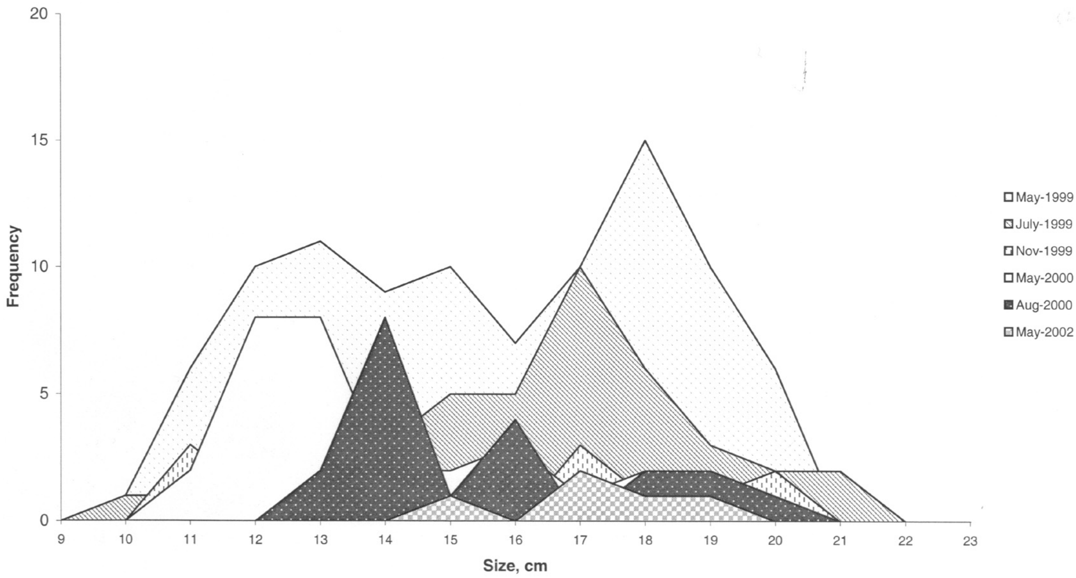

Figure 5. Size distribution of stocked eels in post-stocking survey in River Madum Å recaptured from May 1999 to May 2002.

In Madum Å, tagged eels bigger than 22 cm were never observed (Figure 5) during the study period, suggesting that growth was very limited.

Discussion

Thomassen et al. (2000) tested the use of coded wire tags on eels. They found that retention rates after 28 d were 96.9% for small (3 g) and 99.3% for large (10 g) eels and that the greatest loss (61%) occurred within the first 2 h after marking. Survival of tagged specimens was 100%. Coded wire tags seem to be an appropriate way of tagging eels of this size.

In Madum Å an 85.5% decrease in numbers was found after 9–12 months, and after four years, only 0.4% of the stocked eels were left in the study area. The reduction in numbers is similar to results of Bisgaard and Pedersen (1991), who found a reduction of 84% after one year.

In the tributaries of River Gudenå, the rate of disappearance estimated over 100 d, including mortality and migration, was very high—from 98 to 100% (Table 1). Berg and Jørgensen (1994) found that only 66–92% had disappeared after 100 d. Because natural mortality is a function of size (Ursin 1967), it is not likely that the bigger eels (3 and 9 g) used in this study suffered higher initial mortality than that found by Berg and Jørgensen (1994), who used glass eels or elvers weighing 0.3–1.1 g. Assuming that bigger eels have a lower rate of mortality compared with smaller eels, emigration rather than mortality may explain why eels disappeared from the stocking areas. Upstream migration speed of elvers has been estimated at 0.64 km × day^{-2} (White and Knights 1997). At that speed, stocked eels may leave the stocking areas in River Gudenå in just one day.

The relation of stocking density and poststocking dispersion (Figure 3) suggests that a low stocking rate (<1 eel × m^{-2}) results in the lowest dispersal or disappearance. Therefore, carrying capacity of the streams is important. The carrying capacity of a stream habitat depends upon the availability of both food and shelter. Eels hide in soft bottom substrate, between the roots of trees, and in crevices. Substrates in the study areas consist mostly of sand or gravel. Such habitats possibly lack places to hide compared with habitats with soft bottom and emergent macrophytes, which can be found in the lower and deeper parts of the stocked water systems. These areas are difficult to survey by electrofishing because of increasing water depth, so long-term effects of stocking will have to be assessed by gear that catches large, old eels (e.g., fyke nets and eel traps).

Eels have been shown to grow 2–5 cm a year in Danish streams (Rasmussen and Therkildsen 1979; Bisgaard and Pedersen 1991). In this study, no growth or very little growth occurred. Food availability is not likely a limiting factor, and local landowners and anglers claim that 10–20 years ago, there was a significant eel population in Madum Å. Further, in ongoing stocking experiments in brackish water (Pedersen, unpublished data), eels of the same batches that were stocked in Madum Å have been recaptured at lengths between 35 and 45 cm 2–4 years after stocking, suggesting that the eels stocked in these experiments were of good quality and that the brackish fjord is a better growth habitat.

One obvious difference between these habitats is that the small streams are relatively cold, up to 13°C (Figure 2), whereas shallow brackish habitats may be very close to the optimum temperature for growth (25°C). It therefore seems that the streams may provide a relatively unfavorable habitat. Possibly they are too cold for significant growth and offer little shelter. Therefore, stocking of these streams seems to be of little value, whereas the deeper parts of river systems, including lakes and brackish fjords, seem to offer a better return for stocking effort.

Acknowledgments

I thank my colleagues for valuable help in the field and the anonymous reviewers and the editor for valuable comments on the manuscript. The project was funded by the Danish Rod and License Fund.

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