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Bigger is better in eel stocking measures? Comparison of growth performance, body condition, and benefit-cost ratio of simultaneously stocked glass and farmed eels in a brackish fjord

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A R T I C L E I N F O

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A B S T R A C T

The recruitment of the European eel stock has collapsed and the stock is in a perilous state compared to the reference period between 1960 and 1979. Despite extensive European Union wide stocking efforts towards a stock recovery and a self-reproducing stock, recruitment stagnates at historical low levels. The aim of this study was to compare the most commonly used stocking forms (glass and farmed eels) in terms of their growth performance, body condition, and benefit-cost ratio to test whether stocking efficiency can be increased by the choice of the stocking form. Therefore, glass eels (117 kg) and farmed eels (1040 kg) were purchased in a cost ratio of 1:1 and then marked chemically with alizarin red S prior to stocking in a brackish Baltic Sea fjord. Two years after stocking, farmed eels (374 ± 36 mm; 86.9 ± 25.8 g) showed a significantly higher total length (TL) and body weight (W) than stocked glass eels (323 ± 39 mm; 56.8 ± 25.0 g). Moreover, within age group 2, no statistically differences in the specific growth rates for length and weight were found between stocking forms indicating that the initial advantage in TL and W of farmed recruits is likely to persist. Derived from the recapture ratio, the mortality of age 2 glass eels was 3.9 times higher than in farmed eels indicating a higher benefit-cost ratio for farmed recruits to refill local eel stocks more efficiently. However, the farmed recruits in this study have been found to be infected with the *anguillid herpesvirus 1* which negates the conservation claim specified by the EU regulation.

1. Introduction

In 2003, eel specialists from all around the globe jointly published their findings that all three commercially most important eel species *Anguilla anguilla*, *A. rostrata*, and *A. japonica* revealed an obvious synchronic recruitment collapse (Québec Declaration of Concern, 2003) with minimum levels in the early 2010's (ICES, 2017b). The European Union recognized this dramatic trend and adopted a regulation in 2007 (EC, 2007) which requests its member states to establish eel management plans (EMP) and to take countermeasures that encompass the recovery of the stock of the European eel *A. anguilla*. A key objective of all EMPs is the sustainable attainment of a minimum silver eel escapement biomass of 40% compared to estimated pristine levels. However, despite ten years of Europe-wide management the eel stock stagnates in a perilous state (Dekker, 2016; ICES, 2016b, 2017b). Hence management failed but also external factors (e.g. climate change, trophic interaction, depensation, and habitat loss) are suspected causes for the lack of recovery (Åström and Dekker, 2007).

In defiance of many uncertainties, a conservation measure of high relevance is 'stocking' which is also proposed by the EU. Natural recruits are caught and redistributed to waters with current low recruitment. However, since the artificial eel seed production is still not feasible, this approach is entirely reliant on wild glass eels catches thus mortalities during catch and transport but also after stocking are highly relevant for the evaluation of management measures.

There is evidence that mortality of recruits can be density-dependant (Vøllestad and Jonsson, 1988; Leo and de Gatto, 1996; ICES, 2000; Acou et al., 2011; Bevacqua et al., 2011; ICES, 2016c). The reallocation of natural eel recruits as a conservation measure, therefore, aims at the reduction of the natural mortality by redistribution of those eels that exceed the carrying capacity of the donor habitat. This means in general that eels are caught in waters with relative high natural recruitment (coast of Spain, Portugal, France, Great Britain) and transported to areas of current low abundances (e.g. Baltic Sea riparian states). ICES (2016c) recently defined that a net benefit of stocking measures exists, if this approach leads to a higher silver escapement biomass compared to a scenario, where no action has been taken. In this regard, Brämick et al. (2016) presented evidence that stocking is a key

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management tool to achieve the defined silver eel escapement target in a local inland river system with low natural recruitment at present. Furthermore, on a local level, evidence was found for a long-term net profit from of stocking measures (Wickström et al., 1996). This is, however, still no evidence that the anthropogenic induced increase of a local silver eel biomass actually leads to an absolute increase for the panmictic European stock as whole (ICES, 2016c).

ICES (2016a) advised since 2000 that no fishery and since 2003 no anthropogenic mortality in general, should increase natural mortality and went further for 2017 to the advice that "all anthropogenic impacts" should be reduced to a minimum (ICES, 2017a). Stocking, however, is not an exclusively nature conservation measure but has also an economic aspect is thus also intended to enable the sustainable use of the eel stock (EC No 1100/2007). In order to ensure that eel stocking is not an end in itself, e.g. ICES (2008) strongly recommends chemical marking of all stocked recruits to allow traceability through all life stages and thus estimations about the potential contribution of stocked recruits to future recruitment.

Notwithstanding the underlying objective of a stocking programme—rather stable fishing yields and/or number of potential spawners—the choice of the stocking material is crucial in any case. The most common stocking forms are glass eels (ca. 5.4–9.2 cm long young unpigmented recently caught for the purpose of stocking) and farmed eels (ca. 15–20 cm long elvers on-grown from glass eels in aquaculture facilities).

It was previously shown that smaller eels might be in advantage over larger eels because of better and continuous growth performances but also higher yields per recruit (Simon and Dörner, 2014; Pedersen and Rasmussen, 2016; Pedersen et al., 2017). However, most stocking studies were conducted either under inland, freshwater conditions only (Pedersen, 2000; Pedersen, 2009; Simon et al., 2013a; Simon and Dörner, 2014), the small eels were farmed for several weeks as well before stocking (Pedersen, 2009; Pedersen and Rasmussen, 2016), or only one stocking form was investigated allowing only indirect comparison between studies (Wickström, 1986; Andersson et al., 1991; Bisgaard and Pedersen, 1991; Pedersen, 1998, 2000; Wickström et al., 1996). Moreover, the selection of the recipient habitat is also of major importance, whereby especially costal habitats revealed a high suitability as recipient water also because of lower parasite loads, higher growth rates, and better body conditions compared to eels in fresh water (Edeline et al., 2005; Melià et al., 2006; Lin et al., 2007; Jakob et al., 2009; Marohn et al., 2013; Simon et al., 2013b).

The aim of this study was to compare simultaneously stocked glass and farmed eels in a brackish water system with regard to growth performance, body condition, and benefit-cost ratio after the first two years in the recipient brackish waterbody. Higher recapture rates for farmed eels but better growth performances, and body conditions were hypothesized for glass eels.

2. Material and methods

2.1. Study area

The study area was the Schlei fjord located in northern Germany which covers an area of 5460 ha (54.595976°N, 9.852501°E; Fig. 1). It is a narrow brackish inlet of the Baltic Sea coast, which is characterized by a salinity gradient decreasing from ca. 18–20 at the opening (east) to ca. 3–5 at the innermost station (west). The mean water depth is ca. 2–3 m and the mean water temperature is between 11 and 12 °C (LANU, 2001). The mean Secchi depth during the winter is 0.9 and 1.5 m decreasing in summer times to 0.5–1.2 m, and eutrophic nitrogen (ammonia and nitrate) concentrations of > 1 mg L^{-1} can be found on average (LANU, 2001).

2.2. Stocking material, chemical marking, and health status

Between March 2015 and July 2016 a total of 117 kg of glass eels (approximately 351000 individuals) and 1040 kg of farmed eels (approximately 156000 individuals) were scattered all over the Schlei fjord by local fishermen (Table 1). This corresponds to a numerical proportion at date of stocking of roughly 2.3:1 (glass eels to farmed eels) and a purchase cost ratio of 1:1. This approach enables relative conclusions about the benefit-cost ratio, which would be equivalent at an approximately identical recapture frequency.

The glass eels were imported from England and the farmed eels have been raised in commercial eel farms, whereby used glass eels originated from France. Before stocking the entire stocking material was chemically marked with alizarin red S (ARS; Kullmann et al., 2017b, 2018). The marking induced mortality was consistently low (< 1.0%) and marking success at 100% throughout. Subsequently conducted virus screenings of the farmed stocking material in 2015 and 2016 revealed that both cohorts were found to be positive for the *anguillid herpesvirus 1* (AngHV-1; Kullmann et al., 2017a). The health status of stocked glass eels is not known at date of stocking but on-grown marked glass eels have been found to be infected with AngHV-1 (Kullmann et al., 2017a). Because an unknown amount of unmarked eels were simultaneously stocked in adjacent waters, unmarked eels could not be considered as natural recruits in any case.

2.3. Morphometrical measurements and otolith preparation

For this study a total number of 1005 eels were caught in 2016 and 2017 in the Schlei fjord at various stations (Fig. 1; Table 2). Eels have been purchased from commercial longline fisheries and additionally fyke nets with a mesh-size of 5 mm at the cod end were operated to account for the low catchability of stocked glass eels in the first year after stocking (e.g. Bevacqua et al., 2009). Eels were sacrificed and deep frozen at ca. −20 °C. After thawing the total length (TL) in mm, body weight (W) in g, and liver mass in g were measured and sagittal otoliths were removed by longitudinal dissections of the head, cleaned and stored in plastic tubes for further preparation. Sex was determined according to Tesch and Thorpe (2003). One otolith was used for cohort assignment by preparation according to the "crack and burn" protocol as recommended by ICES (2009, 2011). The annuli (winter rings) were counted and ageing reference date was the individual stocking date arising from the number of annuli (Table 1). The age is presented as number of winter rings (annuli) or days post stocking (dps). For ARS mark detection, the second otolith was cracked on a transversal plane, embedded in thermoplastic wax with the cut surface down (Crystalbond, Buehler®) and ground to the primordium as described by Simon et al. (2013a). These thin section preparations were checked for an ARS mark using a light microscope (Leica DM 2500) equipped with a light source (CoolLED *p*E-300-W) and a light filter for wavelengths between 530 and 580 nm. The ARS mark appears as glowing band that was defined as age zero. The ARS mark is identical to the 'zero band' in glass eels and discernable closer to the core than in farmed eels (Fig. 2).

2.4. Calculation of body condition and growth performance

The body condition using Fulton's condition factor (K) and nutritional status using the hepatosomatic index (HSI) of the stocked recruits was described by calculating K and HSI after Ricker (1975) and Bolger and Connolly (1989) as follows:

$$K = W \times TL^{-3} \times 100$$

and

$$HSI\ (\%) = LM \times W^{-1}$$

Whereby TL is the total length in cm, W the body weight in g, and LM