

Evidence for an autumn downstream migration of Atlantic salmon *Salmo salar* (Linnaeus) and brown trout *Salmo trutta* (Linnaeus) parr to the Baltic Sea

Imre Taal · Martin Kesler · Lauri Saks · Mehis Rohtla · Aare Verliin ·
Roland Svirgsden · Kristiina Jürgens · Markus Vetemaa · Toomas Saat

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Abstract In the eastern Baltic rivers, anadromous salmonid parr are known to smoltify and migrate to the sea from March until June, depending on latitude, climate and hydrological conditions. In this study, we present the first records of autumn descent of brown trout *Salmo trutta* and Atlantic salmon *Salmo salar* from the Baltic Sea Basin. Otolith microchemistry analyses revealed that these individuals hatched in freshwater and had migrated to the brackish water shortly prior to capture. The fish were collected in 2006, 2008, 2009 and 2013 from Eru Bay (surface salinity 4.5–6.5 ‰), Gulf of Finland. This relatively wide temporal range of observations indicates that the autumn descent of anadromous salmonids is not a random event. These results imply that autumn descent needs more consideration in the context of the effective stock management, assessment and restoration of Baltic salmonid populations and their habitats.

Keywords Gulf of Finland · Downstream descent · Salmonid parr · Sr:Ca profiles · Otolith microchemistry

Introduction

Juvenile Atlantic salmon, *Salmo salar*, and anadromous brown trout (sea trout), *Salmo trutta*, stay in their native river usually for at least one to several years (reviewed in Jonsson and Jonsson 2009a). In the Baltic Sea, anadromous salmonids usually smoltify (an adaptation for coping with transition to saline water) and descend the river to the sea in spring. In the Gulf of Finland, anadromous salmonid parr smoltify and migrate to sea from April to June (Kangur et al. 2003a, b; Kesler et al. 2013). The primary regulating factors of the smolting process are photoperiod and ambient temperature (McCormick et al. 1998), whereas the main factors controlling the timing of the smolt run are water temperature, water flow and changes in these parameters (detailed in Jonsson and Jonsson 2009a).

Besides migration in spring, autumn descent of Atlantic salmon parr has been noted in North American and Great Britain populations (reviewed in Ibbotson et al. 2013), with a significant proportion of the juveniles (25 % of the spring smolt run in absolute terms) reported moving to the tidal reaches in at least one study (Pinder et al. 2007). According to Riley et al. (2008), the autumn migrants are not sufficiently physiologically adapted to marine environment. Riley et al. (2009) reported that the adult return rate from autumn-migrating salmon parr appeared to be low. Autumn downstream migration of juvenile anadromous brown trout has been documented in the River Imsa, Norway (Jonsson and Jonsson 2009b). In this case, the survival of autumn descending pre-smolts was very low (Jonsson and Jonsson 2009b). These reports suggest that autumn descending salmonid juveniles may contribute little to the recruitment of the populations. However, it has been suggested (Riley et al. 2009) that the phenomenon of autumn downstream migration still deserves more attention in the context of

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I. Taal (✉) · M. Kesler · L. Saks · M. Rohtla · A. Verliin ·
R. Svirgsden · K. Jürgens · M. Vetemaa · T. Saat
Estonian Marine Institute, University of Tartu, Vanemuise 46a,
51014 Tartu, Estonia
e-mail: imre.taal@ut.ee

L. Saks
Department of Zoology, Institute of Ecology and Earth Sciences,
University of Tartu, Vanemuise 46, 51014 Tartu, Estonia

effective management, assessment and restoration of anadromous salmonid populations and their habitats.

To date, there are no scientific evidence of autumn downstream migration of juvenile Atlantic salmon and anadromous brown trout from the Baltic Sea Basin. Therefore, the stock status estimates are based solely on spring smolt abundance, and monitoring programmes do not account the autumn migrations in the Baltic Sea (ICES 2013). This study reports the first observation of an autumn downstream migration of both Atlantic salmon and anadromous brown trout in the Baltic Sea.

Materials and methods

Juvenile Atlantic salmon and anadromous brown trout were collected from Eru Bay (59°35'N 25°49'E) located at the southern shore of the Gulf of Finland, Baltic Sea (Fig. 1). Surface water salinity of the bay is 4.5–6.5 ‰ (Martin et al. 2003) which is typical for the central part of the Gulf of Finland. Although salmonid river Loobu (Kangur et al. 2003a, b) discharges into Eru Bay, the influence of freshwater to the salinity levels in the area is very low (Martin et al. 2003). Sampling was carried out with gillnets and hand (beach) seine (see Taal et al. 2014 for methodological details) in December 2006 and monthly during ice-free season from March to December 2008, April to December 2009, in November and in December 2013. For all caught individuals, total length (TL) and body mass (TW) were recorded and sex determined by visual examination of gonads. Age was determined by counting the translucent zones from unstained otoliths using a stereomicroscope against dark and light background. To infer migration patterns (reviewed by Elsdon et al. 2008), sagittal otoliths were also removed, cleaned and stored in dry microtubes.

Before the chemical analysis, otoliths were ground from the sulcus side until the core area and primordium became visible. Otolith strontium to calcium ratios (Sr:Ca) were quantified with laser ablation inductively coupled plasma mass spectrometry. The laser was set at 7 Hz with a 40- μ m spot size and a scan speed of 5 μ m s⁻¹. A continuous line scan was traced from the core (excluding the primordium) to dorsal edge of the otolith. Data were handled following the methods of Miller (2007) as described in Rohtla et al. (2014).

Results

One anadromous brown trout parr was caught on 10 December 2008, by the hand seine haul (no otoliths were collected from that individual). Two additional brown trout were caught with hand seine on 14 November and one in

15 November 2009. All these individuals were females. The first male autumn descending trout parr was collected on 28 December 2013, with hand seine (Table 1). One trout individual was aged as underyearling and all the others as yearlings (Table 1).

One female autumn descending Atlantic salmon parr was caught on 7 December 2006, with hand seine. A second female salmon was collected on 15 November 2009, with gillnet, with a third female salmon collected on 27 December 2013, using a hand seine. The first descending spent male salmon parr was collected on 28 December 2013, with gillnet (Table 1). Parr status of both salmon and trout was confirmed by visual observation of strong markings accompanied with no signs of smoltification.

Otolith Sr:Ca profiles confirmed that all sampled individuals hatched in freshwater (Fig. 2). Still, the peaks in the beginning of the Sr:Ca profiles represented maternally derived seawater signal (Kalish 1990). According to Miller (2011), the change in otolith Sr:Ca profile becomes evident during 2–3 days and reaches a plateau latest 2 weeks after the smolt has migrated to the sea. Two trout individuals in

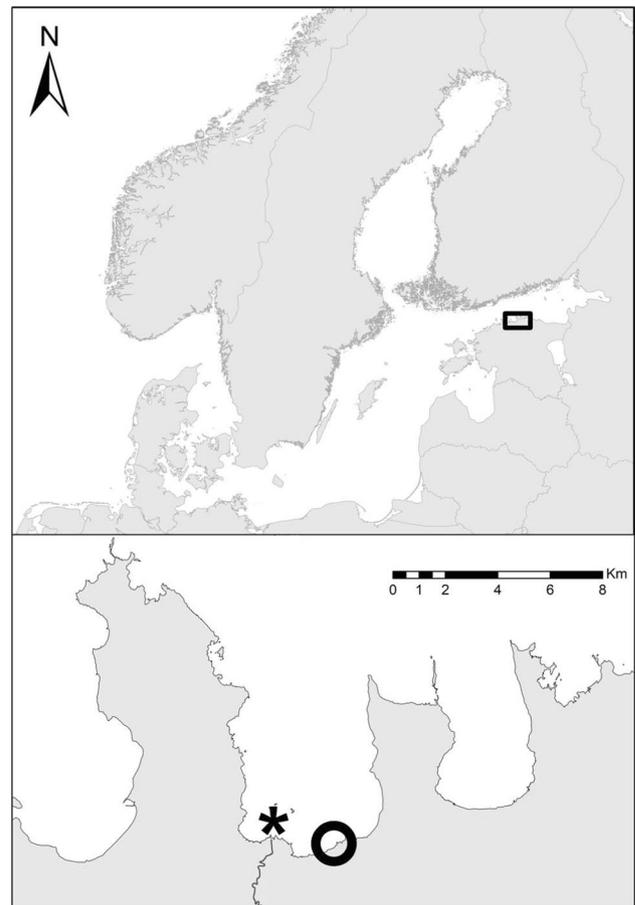


Fig. 1 Map of the study area (circle location of the sampling site, asterisk river mouth of the Loobu River)

Table 1 Individual parameters of autumn descending Atlantic salmon and anadromous brown trout parr

Species	Age	Sex	Maturity	TL	TW	Sea days	Date
<i>S. salar</i>	Underyearling	Female	Juvenile	130	17.7	14–28	7 December 2006
<i>S. salar</i>	Yearling	Female	Juvenile	148	26.9	2–7	15 November 2009
<i>S. salar</i>	Yearling	Female	Juvenile	140	21.4	2–7	27 December 2013
<i>S. salar</i>	Yearling	Male	Spent	155	29.6	2–7	28 December 2013
<i>S. trutta</i>		Female	Juvenile	101	7.9		10 December 2008
<i>S. trutta</i>	Underyearling	Female	Juvenile	98	8.9	<2–3	14 November 2009
<i>S. trutta</i>	Yearling	Female	Juvenile	121	17.8	2–7	14 November 2009
<i>S. trutta</i>	Yearling	Female	Juvenile	146	26.9	<2–3	15 November 2009
<i>S. trutta</i>	Yearling	Male	Juvenile	155	27.1	2–7	28 December 2013

TL is presented in millimetres and TW in grams

our data set had descended to the sea less than 2–3 days (Table 1) before capture (i.e. no sea water signal in the profile; Fig. 2a). Most individuals had descended to the sea within 2–7 days (Table 1) prior to capture (i.e. minimal to moderate sea water signal; Fig. 2b). Only one salmon (Table 1) had descended to the sea more than 2 weeks (but no more than 4 weeks) before the capture (i.e. plateau in the profile; Fig. 2c).

Discussion

Results from the present study show that the autumn descent of anadromous salmonids occurs in the Baltic Sea. The parr phenotype of autumn descending anadromous brown trout and Atlantic salmon in this study is in accordance with previous results reviewed, e.g. by Youngson et al. (1983), Riley et al. (2008) and Jonsson and Jonsson (2009b). The autumn migration of Atlantic salmon parr has been associated with high flows (Youngson et al. 1983), but it is not clear why only a proportion of the population follows the autumn migration strategy. It is also unclear whether these two groups of fish differ in their genetic origin (Ibbotson et al. 2013). Ibbotson et al. (2013) reviewed a number of potential mechanisms that trigger autumn migration of Atlantic salmon, including intrinsic factors such as size and position in the dominance hierarchy and extrinsic factors associated with density and habitat, related to the supply of food, cover (shelter availability) and the presence of predators. These hypotheses may also be relevant for brown trout as the phylogeny and life history of this species are similar to Atlantic salmon (reviewed by Jonsson and Jonsson 2009b, but see also Limburg et al. 2001).

To our knowledge, our results are the first documentation of autumn downstream migration of juvenile Atlantic salmon and anadromous brown trout from the Baltic Sea Basin. However, it has been reported that fry and parr of anadromous brown trout from small Gotland streams (with high number of spawners and decreasing water levels

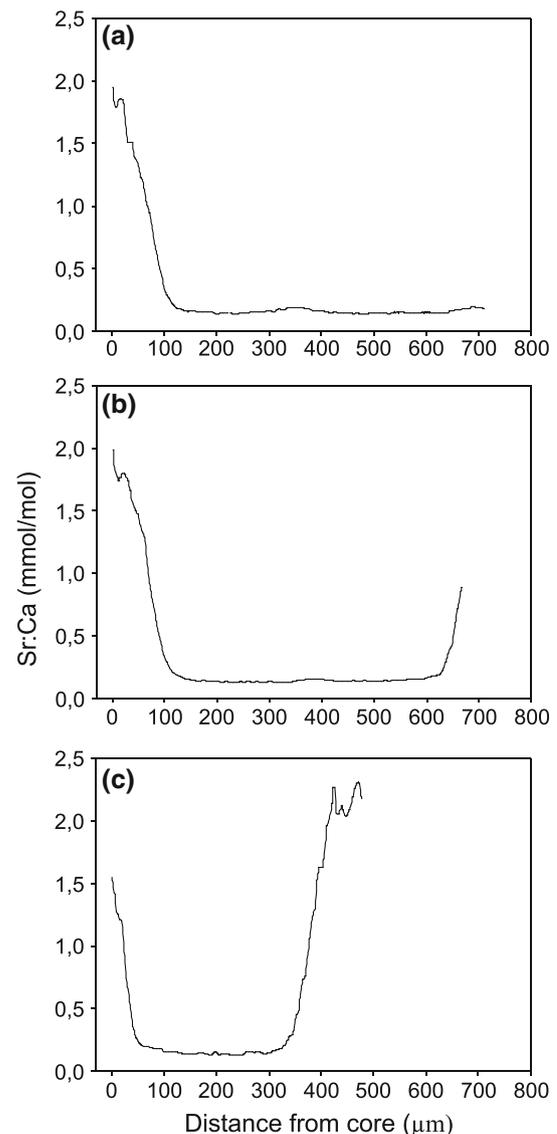


Fig. 2 Examples of Sr:Ca profiles. **a** Anadromous brown trout collected from the sea on 14 November 2009, with no seawater signal; **b** salmon collected from the sea on 28 December 2013, with moderate seawater signal; **c** salmon collected from the sea on 07 December 2006, with stabilized seawater signal. The peaks in the beginning of the Sr:Ca profiles represent maternally derived seawater signal (Kalish 1990)

during spring and summer) move to sea soon after hatching in spring and early summer (Landegren and Vallin 1998; Landegren 2001; Landergren 2004). Still, these observations from Gotland do not contradict the conclusions of the present study, as we report data on autumn migration of juvenile anadromous brown trout, not on spring–summer descent of parr immediately after hatching.

Riley et al. (2008) reported that autumn-migrating Atlantic salmon parr are not yet physiologically adapted to saline water (i.e. expected survivability in the ocean is very poor) and therefore overwinter in estuaries. Still, autumn migrants have been detected returning as sea run adults (Riley et al. 2009). In the River Imsa, few of the juvenile anadromous brown trout descending to the estuary in autumn and winter survived until adulthood and returned to the river (Jonsson and Jonsson 2009b). However, it has been experimentally demonstrated (Landegren 2001) that the brackish Baltic Sea water (6–7 ‰, e.g. around Gotland island) is not a physiological obstacle for the survival of early out-migrating anadromous brown trout parr. Moreover, these results (Landegren 2001) suggested that anadromous brown trout parr descending from freshwater to the brackish Baltic coastal zone, without smolting, may experience little or no physiological cost in survival and growth. The Gulf of Finland in the Baltic Sea is a brackish ecosystem with very low surface water salinity, increasing from <1.0 ‰ in the East to 6.0 ‰ in the West (Lappalainen et al. 2000). Thus, it may be possible for autumn descending Atlantic salmon parr to survive and thrive in this expansive brackish marine environment, while the sea survival of brown trout parr may be higher than previously reported from more saline regions (Jonsson and Jonsson 2009b).

In conclusion, our results suggest that autumn descent of salmonid parr in less-saline parts of the Baltic Sea need more consideration at least in the context of life history individual recruitment strategy and the management and restoration of salmonid populations and their habitats.

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