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RESEARCH ARTICLE

Age and size of migrating Atlantic salmon, *Salmo salar* L., and sea trout, *Salmo trutta* L., smolts in Lithuanian rivers

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Abstract. The aim of the present study was to determine the mean size and age of migrating salmon, *Salmo salar* L., and sea trout, *Salmo trutta* L., smolts in three rivers of the Nemunas River drainage area from different climatic sub-regions in Lithuania. Research indicates there were significant differences of migrating fish age and size between stocked and natural smolt populations. In natural populations salmon and sea trout smolts aged 2+ dominated, but up to 82% of all migrating smolts of the stocked population in Siesartis River were aged 1+. The artificially-reared salmon and sea trout smolts in the Siesartis River were significantly larger than wild fish in the 1+ age group of migrants, and, accordingly, they reached smolt size and were ready to migrate earlier. The high density of salmonid parrs in the Siesartis River and intraspecific competition could have also prompted 1+ age group smolts to migrate. It is hypothesized that the phenomenon of early smolt migration in the Siesartis River could have been a local adaptation to the long migration route, or it could have resulted from density-dependent competition caused by imbalanced stocking programs.

Keywords: wild population, smolt migration, age, stocking impact, stream salmonids

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Introduction

There are sea trout, *Salmo trutta* L., and salmon, *Salmo salar* L. populations in 642 and 57 rivers around the Baltic Sea, respectively, of which the majority (508 and 29) host sustainable sea trout and wild salmon populations. The majority of natural salmon populations inhabit the southeastern and eastern coasts of the Baltic Sea in Russia, Estonia, Latvia, and Lithuania (ICES, 2010). Salmon and sea trout smolts have been well studied and documented in the western part of the Baltic Sea region (Lundqvist et al. 1988, Klemetsen et al. 2003, Serrano et al. 2009); however, smolt studies from the southeastern Baltic have not been as detailed (Chełkowski and Chełkowska 1995, Borzęcka 1999, Kesminas and Virbickas 2003).

In the eastern Baltic rivers smolt migration usually occurs from March until June, depending on latitude, climate, and hydrological conditions (Mitans 1976, Kesminas et al. 2000, Klemetsen et al. 2003). In general, catadromous migration can last from two to six weeks, but in the rivers of the Baltic Sea region the main run takes only one to three weeks (Mitans 1976, Hvidsten et al. 1995, Kesminas and Virbickas 2003). Smolt size and age during migration vary greatly among populations. In the Baltic Sea region the mean smolt length typically ranges from 100 to 220 mm, with the majority in the 2+ to 4+ age

Table 1
Main characteristics of the investigated sub-regions and rivers (Gailiušis et al. 2001, LHMT, 2010)

River	Mera River (Žeimena system)	Siesartis River (Šventoji system)	Veiviržas River (Minija system)
Location (latitude / longitude)	N 55 01 42.93 E 25 50 51.05	N 55 17 32.57 E 24 51 11.00	N 55 30 14.18 E 21 20 49.39
Distance from the Baltic Sea (km)	484	368	76
River length (free flow) (km)	60.2 (60.2)	64.1 (46.6)	79.0 (67.9)
Tributary area (km^3)	206	615.7	686
Discharge ($m^3 s^{-1}$)	1.94	5.13	9.06
Mean channel gradient ($m\ km^{-1}$)	1.32	1.45	1.55
Region	Southeastern Highland	Central Lowland	Coastal Lowland region
Mean annual air temperature (°C)	+ 5.7	+ 6.0	+ 6.9
Duration of periods without freezing (in days)	151	143	174
Annual precipitation rate (mm)	559	585	643

groups (Chełkowski and Chełkowska 1995, Borzęcka 1999, Klemetsen et al. 2003, Dębowski et al. 2010, Kesminas 2010). The age composition of migrating salmonids depends on fish size and local climatic conditions (Power 1981) or even population density (Elliot 1994, Jenkins et al. 1999).

The rivers of the eastern Baltic region are important for anadromous salmonid reproduction, and they contribute significantly to the wild stocks of sea trout and Atlantic salmon in the Baltic. Many natural, self-reproducing sea trout (stream-dwelling and anadromous) and some Baltic salmon populations occur in Lithuanian rivers. Some salmonid populations in the Nemunas River basin are unique in that they traverse one of the longest migration routes in Europe, as do those in the Žeimena and Mera rivers or the recently stocked and numerous populations in the Siesartis and Vilnia rivers. In the Žeimena and Mera rivers the unobstructed migration route stretches for more than 540 km, and for more than 400 km until the first fish ladders in the Siesartis and Vilnia rivers. Other well-known, long, unobstructed salmon and sea trout migration routes in Europe include those in the Torne and Tana rivers, but these differ from the Lithuanian routes in terms of latitude, fish species composition, water quality, temperature, and flow regimes. Therefore, it is important to understand the main patterns of long distance catadromous smolt migration in eastern Baltic rivers. The current study focuses on migrating salmon and sea trout smolt age and size analysis in different rivers of the Nemunas basin from the coastal Veiviržas to the distant Mera rivers, which are located at 76 and over 480 km from the Baltic Sea, respectively.

Materials and methods

Migrating Atlantic salmon and sea trout smolts were caught in three rivers in different climatic sub-regions of Lithuania (Gailiušis et al. 2001). The rivers chosen were as follows: the Mera River (1999-2010 research period) in the Southeastern Highland region; the Siesartis River (2005-2010) in the Central Lowland region; the Veiviržas River (1999-2007) in the Coastal Lowland region (Fig. 1, Table 1). The Mera River, as well as the Žeimena River, was never stocked with salmon or sea trout, therefore its populations are considered purely natural. The Veiviržas River also has a natural sea trout population, but salmon is absent from this river basin. The Siesartis River has been stocked with salmon and sea trout since the native populations were on the verge of total extinction. Salmon stocking was performed during the 2002-2005 period, and sea trout was stocked during the 2002-2006 period and in 2008 until both populations had fully recovered to sustainable levels. Stocking was performed using

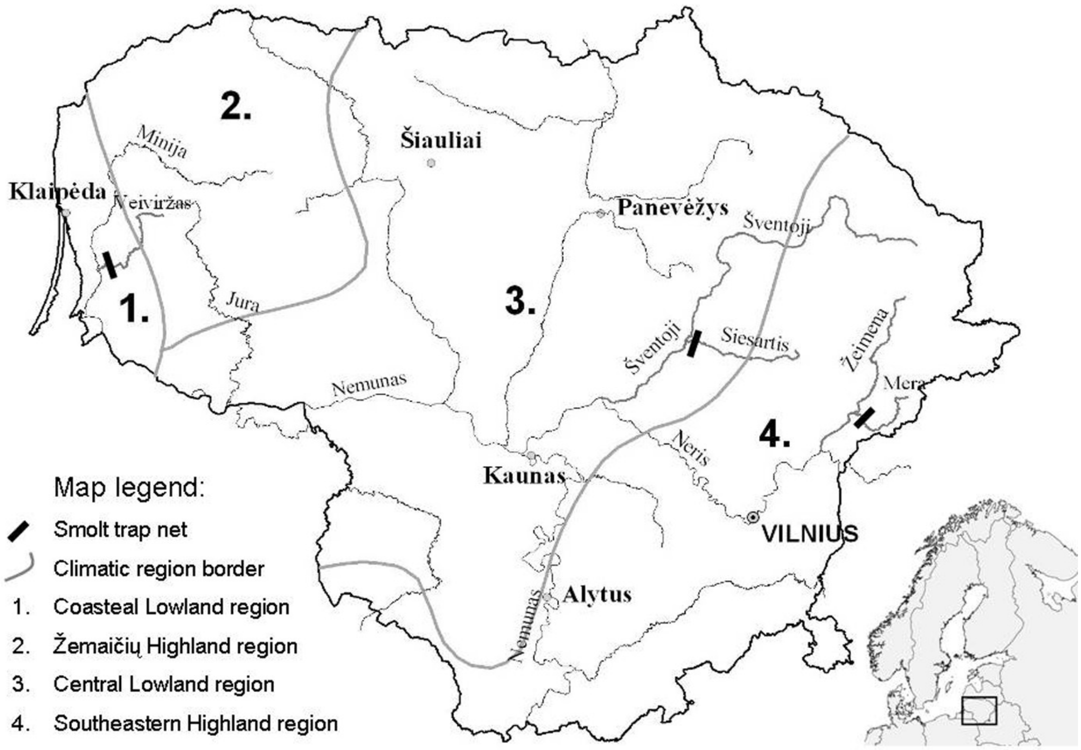

Figure 1. Map with Lithuanian climatic sub-regions (Gailiušis et al. 2001) and study locations.

salmonid eggs that were collected from spawners caught during the pre-spawning migration in the Nemunas basin. The eggs were incubated in a semi-natural temperature regime which reflected the ambient temperature of the Žeimena River unless the water temperature dropped below 4.0°C (minimal standard temperature in hatchery). Larvae and fry were fed artificially until stocking, which was usually performed in mid May. The fry were released into pools below rapids at stocking densities always lower than 2 ind. m^{-2}. The salmonid fry were released at the same sites every year. The salmonid fry used for stocking were significantly larger than natural fry (Stakėnas et al. unpublished). The study period in the Siesartis River was divided into two: during stocking (DS) and after stocking (AS). The DS period covers one year after the last stocking for 1+ smolts, and two years for two 2+ smolts. The size and age structure of migrating smolts from these two periods were analyzed separately.

The smolts were caught using smolt traps (22 m wide and 3 m height) installed to span the width of the river close to its mouth. The trap wings were made from 12 mm mesh with a hoop-net in the center equipped with an 8-mm mesh bag ensuring that even the smallest migrating smolts were caught. Smolt trapping started after the spring flood when the water level was low enough to allow the installation of the trap. The sampling usually started in late March or the beginning of April depending on hydrometeorological conditions during the study period, and sampling was performed randomly every two to three days during the migration period. The water temperature range at the beginning of sampling was 3.5-4.8°C and more than 16°C at the end of sampling. The smolt migration studies lasted from four to six weeks in spring every year, while the majority of smolts were caught during a period of one to three weeks. Migrating salmon and sea trout individuals caught in the trap during the smolt migration season were identified as smolts irrespective of the degree of body silvering, since some of the migrating individuals reached the sea before silvering (Kesminas et al. 2000, Nilsen et al. 2003).

Table 2
Mean abundance (ind. 100 m^{-2}) of salmonids in the Mera, Siesartis, and Veiviržas rivers and the stocking program in the Siesartis River with the quantities of fry stocked

	Veiviržas River	Mera River		Siesartis River		Quantities of fry stocked	
Year	Sea trout	Salmon	Sea trout	Salmon	Sea trout	Salmon	Sea trout
1999	17.27	0.00	2.83	nd*	nd*	-**	-
2000	17.11	0.13	6.39	1.84	2.09	-	-
2001	7.59	0.27	2.20	3.70	1.30	-	-
2002	9.30	0.08	5.20	2.50	2.49	5000	-
2003	10.95	0.00	3.30	0.45	0.85	10000	-
2004	8.76	0.00	4.20	3.40	3.90	13000	3000
2005	11.40	0.00	0.19	10.30	2.32	10000	6000
2006	10.60	0.05	1.81	1.21	2.00	-	5000
2007	8.39	0.44	9.35	7.50	3.53	-	-
2008	40.83	0.50	12.04	36.40	6.97	-	4000
2009	18.20	0.25	9.70	48.10	2.44	-	-
2010	6.05	0.00	3.26	3.55	0.81	-	-

*no data; monitoring surveys in Siesartis River started from 2000 year
**no stocking

All of the smolts caught were anesthetized with 2-phenoxy ethanol (0.3-0.4 ml l^{-1}), and the total length (TL, mm) and body weight (W, g) of each fish were recorded and a few scales were collected for age determination. The age of the fish was determined by scale analysis according to the methods proposed by Pravdin (1966) and Thoresson (1993). Random samples collected in 2005 and 2006 for salmon and in 2007 and 2009 for sea trout in the Siesartis River were analyzed to determine the share and size differences between artificially-reared and natural smolts. Reared and natural smolts were identified using remnant imprints and physiological differences such as opercular malformations, deformed or undeveloped dorsal fins, visual morphopathological evaluation of the liver, etc.

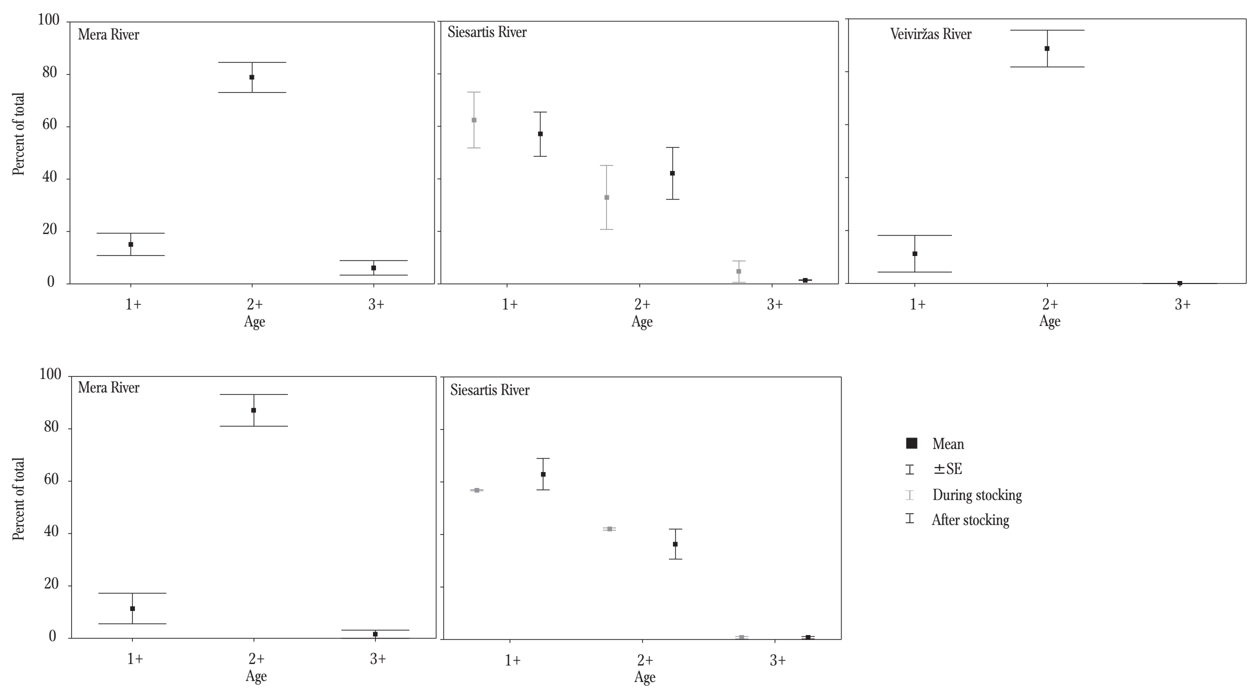

Figure 2. Sea trout (upper graphs) and salmon (lower graphs) age structure in the investigated river populations.

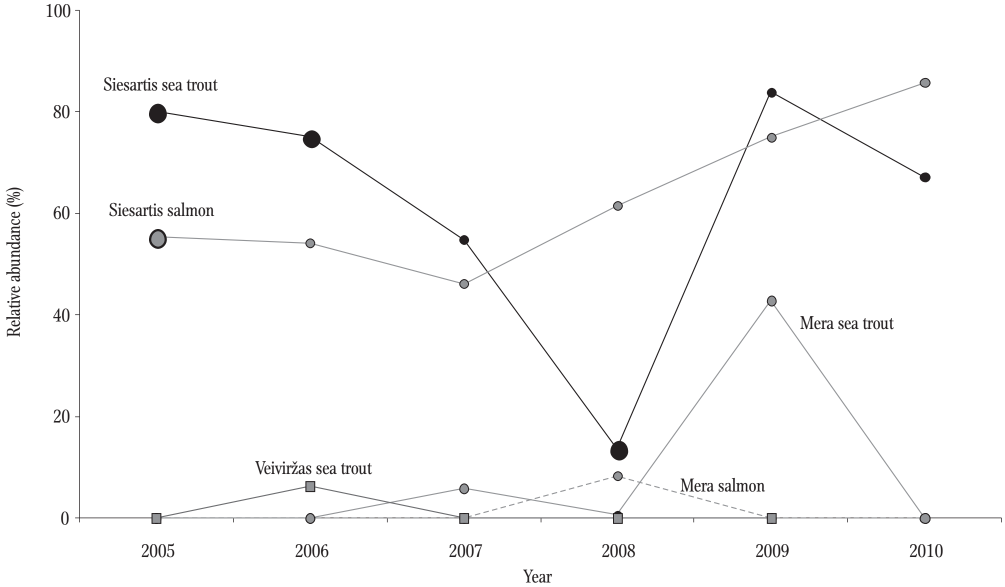

Figure 3. Share of 1+ aged salmonid smolts in the investigated rivers during the research period. Years when fry of *S. salar* or *S. trutta* were stocked into the Siesartis River are indicated by large dot.

according to developed methods (Soivio et al. 1988, Domagala et al. 2005, Kazlauskienė et al. 2006, Kazlauskienė and Vosilienė 2006, Virbickas et al. 2009).

Migrating smolt abundance, size, and age were compared with salmon and sea trout juvenile abundance in the investigated rivers (Table 2), which were determined during annual monitoring surveys on salmonid juveniles at two to three electrofishing sites in the Mera and Siesartis rivers, and at four to five sites in the Veiviržas River (Kesminas 2010, Kontautas 2010). The Zippin method of two or three removals was used to estimate juvenile abundance (Zippin 1958). All of the fish, except those taken for physiological analysis (n = 23), were released back to the river at the sampling site to allow them to continue their migration to the sea. STATISTICA 6® was used for statistical data analysis, and the Kruskall-Wallis test was used to compare the samples.

Results

During the 1999-2010 period a total of 284 salmon and 947 sea trout smolt specimens were caught: 62 salmon and 408 sea trout specimens from the Mera River; 222 salmon and 452 sea trout specimens from the Siesartis River; 87 sea trout smolt specimens from the Veiviržas River. All of the salmon and sea trout smolts caught during the 1999-2010 period were aged 1+ to 3+. The migrating sea trout smolts in the Veiviržas and Mera rivers were dominated by the 2+ age group with a mean share of 88.8% (range 43-100%) and 78.8% (range 57-100%), respectively (Fig. 2). In the Mera River, salmon smolts aged 2+ also dominated with a mean share of 89.1% (range 50-100%) (Fig. 2). In contrast, the migrating smolts in the Siesartis River were predominant by the 1+ age group with a mean share of 62.0% (range 13.7-83.8%) for sea trout and 62.8% (range 46.2-85.7%) for salmon (Fig. 2). Stocked fish contributed a significant amount to the numbers of migrating smolts in the Siesartis River with a mean (± SE) share of 19.5 ± 5.5% of the salmon and 13.2 ± 6.8 % of the sea trout populations. The share of 1+ age salmonid smolts varies between rivers (Fig. 3). The annual variations and differences between the rivers were significant.

The share of salmon and sea trout smolts age 3+ was negligible, and the number of individuals from the Siesartis and Veiviržas rivers was too small for statistical analysis (1 salmon and 14 sea trout from the Mera and 2 salmon and 5 sea trout from the

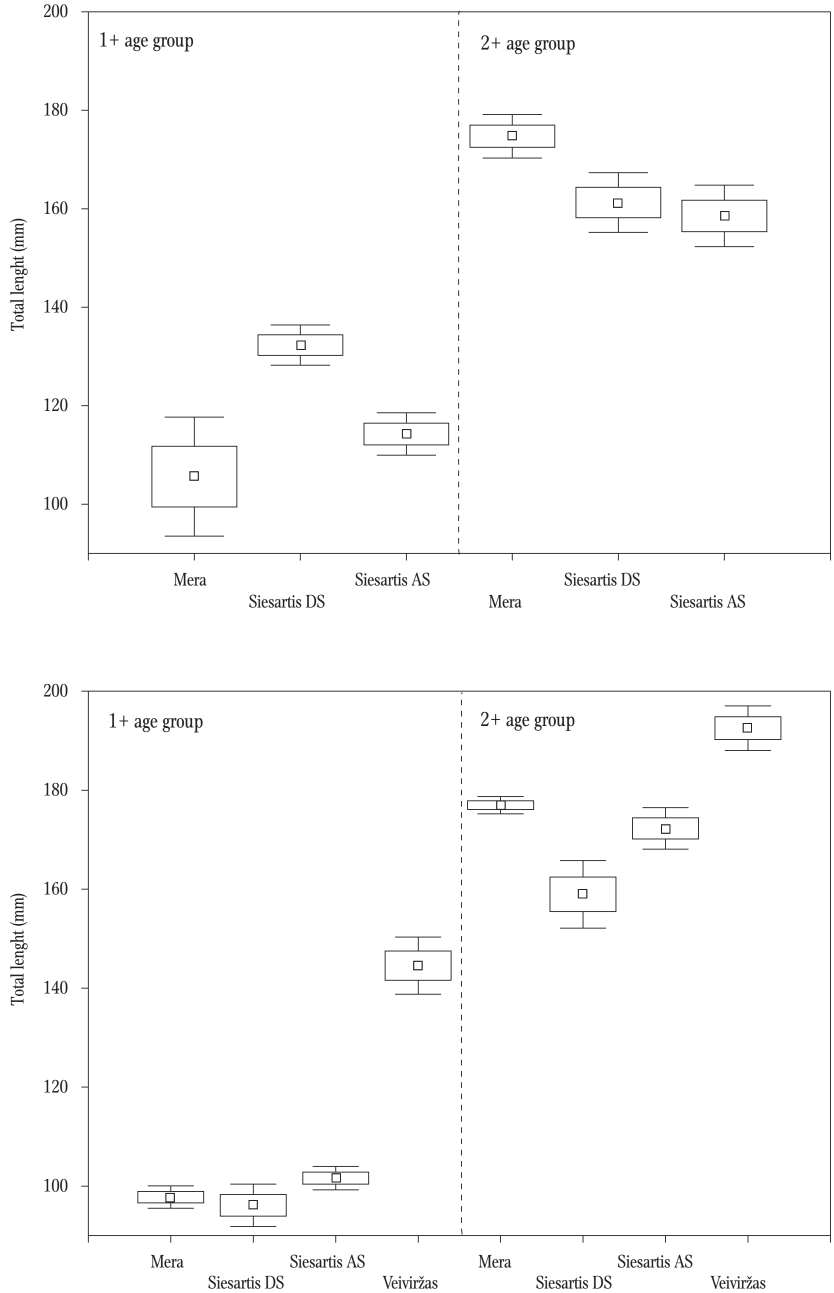

Figure 4. Total length of *S. salar* (upper graphs) and *S. trutta* (lower graph) smolts in the investigated rivers. Dot represents the mean (central tendency), large box represents the mean ± SE, and whiskers represent the mean ± 1.96 SE.

Siesartis rivers, while there were no 3+ age fish in the Veiviržas River). Therefore, data regarding smolt age 3+ were omitted from further analysis. The sea trout smolts age 1+ from the Veiviržas River with mean TL of 145 ± 3 mm (n = 9) were significantly larger compared with smolts of the same age group from the Mera River which measured 98 ± 1 mm TL (n = 35) (Kruskall-Wallis test, $P < 0.0001$), and they were significantly larger compared with those from the Siesartis River at 100 ± 1 mm TL (n = 269) (Kruskall-Wallis test, $P < 0.0001$, Fig. 4). The size of sea trout smolts age 1+ from the Siesartis River differed statistically significantly in the DS and (mean TL 99 ± 1 mm; n = 207) and AS (mean TL 105 ± 2 mm; n = 62) periods (Kruskall-Wallis test, $P < 0.008$). The mean TL of the 2+ age group sea trout smolts in the Veiviržas River was 193 ± 2 mm (n = 78), which was also significantly larger compared to that in the Siesartis River (Kruskall-Wallis test, P < 0.0001) where the mean TL was 169 ± 2 mm (n = 178), and was significantly larger than in the Mera River (Kruskall-Wallis test, P < 0.0001) where the mean TL was 177 ± 1 mm (n = 359). However, in the Siesartis River the size of the 2+ age group sea trout smolts differed statistically significantly (Kruskall-Wallis test, P < 0.001) in the DS (mean TL 171 ± 2 mm; n = 151) and AS (mean TL 154 ± 4 mm; n = 27) periods. The size patterns of salmon and sea trout smolts in the Siesartis River were similar (Fig. 4). In the Siesartis River, the size of 1+ age group salmon smolts in the DS period were statistically significantly (Kruskall-Wallis test, P < 0.001) larger (mean TL 132 ± 2 mm; n = 49) in comparison to the AS period (mean TL 114 ± 2 mm; n = 88). Salmon smolts age 1+ from the Mera River population at a mean TL of 106 ± 6 mm (n = 5) were significantly smaller compared to smolts of the same age from the stocked Siesartis River population (Kruskall-Wallis test, P < 0.001; n = 49); however, there were no significant differences (Kruskall-Wallis test, P = 0.276; n = 88) between AS salmon smolts from the Siesartis River. Similarly to the sea trout smolts, salmon smolts aged 2+ from the Mera River population with mean TL 175 ± 2 mm (n = 56) were statistically significantly larger (Kruskall-Wallis test, P < 0.001) compared to same age group of salmon smolts from the Siesartis River in the DS period (mean TL 162 ± 2 mm; n = 59), and they were significantly larger (Kruskall-Wallis test, P < 0.01) compared to the salmon smolts from the AS period (mean TL 160 ± 5 mm; n = 24). Based on sub-sample analysis, smolts originating from the hatchery were statistically significantly larger than wild fishes for both salmon (Kruskall-Wallis test, P < 0.001) and sea trout (Kruskall-Wallis test, P < 0.001). Despite the fact that the mean TL of hatchery salmon and sea trout smolts aged 1+ were significantly larger compared to the same age group of wild fishes, no differences in migration time or intensity were noted.

Discussion

The salmonid juvenile densities in all the rivers investigated were highly variable during the research period, but they never exceeded >3 ind. m^{-2} (Mortensen 1977), at which lethal density-dependent regulatory mechanisms, such as disease or high competition for food resources among sea trout and salmon, could occur (Kormondy 1992, Le Cren 1973, Elliott 1994). Therefore, the substantial differences in smolt size and dominant age classes in the rivers investigated were probably dependent on factors other than density.

The migrating sea trout smolts in the Veiviržas River (coastal lowland) were significantly larger in comparison to those in the Mera (southeastern highlands) and Siesartis (central lowland) rivers. This might have occurred because of the more preferable conditions including the higher annual water temperature and longer periods free from freezing, which are typical of coastal lowland regions (Gailiušis et al. 2001). Comparable results have been reported by other authors (Jensen and Johnsen 1986, Klemetsen et al. 2003), and salmon smolt growth rate differences have been ascribed to the active feeding period or the impact of the winter season. It is known that better growth is linked to the younger age of juveniles at migration, which is mainly dependent on the duration of the growing season (Power 1981). On local scales, deviations from this general trend can occur depending on other climatic and/or hydrological factors (Power 1986). However, growth differences in the southeastern highland and central lowland regions cannot be explained based only on the very similar climatic conditions of these regions. Thus, other factors such as different environmental conditions could likely have played a significant role. The highland region is dominated by sandy soils containing benthic biocenoses that are less productive than those in the loamy and sandy-loamy soils of the central and coastal lowland regions (Pliūraitė 2006). The predominant food source of juvenile salmonids is the benthos (Pliūraitė 2006), therefore, the lesser amounts of available food could be main factor for reduced growth in the Mera River. Furthermore, the combination of a milder climate together with food availability could explain the sea trout size in the Veiviržas River.

High population density has a negative effect on the growth of juvenile salmonids (Jenkins et al. 1999), and individual variation in growth rates normally decreases with fish density in streams, probably as a consequence of intraspecific competition (Elliott 1994). Thus, the considerably higher salmonid parr density in the Siesartis River compared to that in the Mera or Veiviržas rivers might have negatively affected growth and triggered the substantial migration of young smolts, since up to 85% of all the migrating smolts in the Siesartis River were in the 1+ age group. In Europe, the mean age of migrating salmon and sea trout smolts was between the 2+ and 3+ age groups, while mean total length was within the 150-200 mm range (Hutchings and Jones 1998, Klemetsen et al. 2003); however, smaller, younger migrating individuals were not the exception (McCormick et al. 1985, Dutil and Coutu 1988). It is possible that young migrating smolts in the Siesartis River could have been present as a consequence of the stocking program. That the mean size and age of migrating smolt is affected by stocks of artificially-reared fishes is known from other salmonid populations in Europe (Piggins and Mills 1985, Klemetsen et al. 2003). In Scottish rivers it was noted that reared fishes can drastically change the age structure of migrating salmonids, as the faster growing reared fishes reach critical smolt size and physiological readiness for migration to the sea when in the 1+ age group (Piggins and Mills 1985). The share of 1+ smolts can increase from 10 to 40% after stocking. The impact of stocking on the age structure of migrating fish has also been observed in other countries (Klemetsen et al. 2003).

The present study revealed that reared 1+ age group salmon and sea trout smolts were statistically significantly larger than natural specimens from the same climatic sub-region. The possible impact of stocking on migrating sea trout smolt age structure was obvious from the high fluctuations in the share of 1+ age group sea trout smolts in the DS and AS periods (Fig. 3). The share of 1+ age group sea trout smolts fluctuated drastically (Fig. 3) because of the impact of stocking. In 2008 one year after stocking ended, the share of 1+ age group smolts decreased significantly, but in 2009 it increased drastically as the result of the stocking program being reinstated (Table 2, Fig. 3). These results address the correlation between the abundance of parr that had been stocked and their earlier emigration from the river as determined by Crisp (1993). However, salmon smolts did not demonstrate similar patterns in the share of dominant migrating age groups as did the sea trout in the Siesartis River.

Because of the very long migration route, the catadromous migration of smolts aged 1+ might take more than one season with standstills occurring in major rivers for feeding and wintering. According to national monitoring data, higher abundances of salmon and sea trout juveniles and the dominance of 1+ age group individuals below the Siesartis River mouth in the Šventoji River, and below the Mera inflow into the Žeimena River in comparison to the mean salmonid abundance in this basin (Kesminas 2010) could partially support this hypothesis. It is also notable that no 1+ age group salmon or sea trout smolts were caught in the Curonian Lagoon or in the Baltic Sea coastal waters during 1999-2010 (Kesminas 2010). However, the hypothesis mentioned previously does not explain the smolt age structure in the Mera River, especially because the migration route from the Mera River is longer in comparison to that in the Siesartis River.

Salmonid juveniles prepare to migrate when they reach a certain smolt size (L'Abée-Lund 1989, Økland et al. 1993, Bohlin et al. 1996, Klemetsen et al. 2003). The present results revealed that artificially-reared smolt were larger than natural fish, and that they could attain smolt size earlier. Consequently, they could migrate at a younger age; however, the share of artificially-reared smolts in the Siesartis River did not substantiate such a high share of migrating smolts from the 1+ age group. Younger, smaller sized smolts migrating from the stocked Siesartis River could have resulted from the stocking program, in which case the spawners from distant rivers were mixed to produce progeny, and this could have led to reduced genetic adaptability (Ferguson 2007, Garcia de Leaniz et al. 2007) which consequently induced younger smolt migration. More comprehensive studies are necessary to determine the main reasons for the phenomenon of early migration from natal rivers.

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Aurhor contributions. K.S., and T.V. designed and performed smolt monitoring during all seasons of investigation in Siesartis and Mera rivers; N.N. represents data from Veiviržas River. All authors take part on hypothesizing main ideas of research. Principal impact on statistical analysis of collected data was made by S.S. and T.V; K.S. wrote the paper.

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