Comparison of density, mean length, biomass and mortality of Atlantic salmon (*Salmo salar* L.) juveniles between regions in Iceland

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ABSTRACT

Long-term data series on relative density, mean length, relative biomass and mortality rate of juvenile salmon from four main salmon regions in Iceland were analysed. Differences were found in the estimated relative density and biomass between juvenile year classes. Significant differences were found in mean length, density and biomass among regions for both 1+ and 2+ juveniles. It was concluded that different environmental conditions play a major role in explaining this variability. Average estimated mortality rate between 1+ juvenile and the corresponding 2+ cohort a year later was higher in the southern rivers than in the northern rivers, and was explained by an underestimate of 1+ in some years in the northern rivers. The higher mortality rate of 2+ / 3+ than 1+ / 2+ in the NE area supports this explanation.

Key words: Different regions, Iceland, electric fishing, life history traits, long-term data

YFIRLIT

Langtíma gagnaraðir um þéttleika, meðallengd, lífþyngd og dánartíðni seiða Atlantshafslax (Salmo salar L.*)*

Langtíma gagnaraðir um þéttleika, meðallengd, lífþyngd og dánartíðni laxaseiða voru skoðaðar í fjórum megin laxahéruðum landsins. Umtalsverður munur fannst í vísitölu þéttleika og lífþyngd á milli árganga seiðanna. Marktækur munur fannst einnig í meðallengdum, þéttleika og lífþyngd milli landssvæða, bæði hjá eins árs og tveggja ára gömlum seiðum. Sú ályktun er dregin að mismunandi umhverfisþættir skýri verulegan hluta þessa breytileika. Dánartíðni frá 1+ seiðum til 2+ seiða árið eftir var meiri á Suðvesturlandi heldur en á Norður og Austurlandi. Það er skýrt með vanmati á eins árs seiðum í sumum árum á norðursvæðunum vegna smæðar seiðanna. Hærri dánartíðni reyndist vera milli 2+ seiða til 3+ seiða árið eftir heldur en milli 1+ og 2+ seiða á Norðausturlandi, sem styður þá skýringu.

INTRODUCTION

Long-term data series on population size, density and biological characteristics of individuals are valuable and often required for effective fisheries research and management (Elliot 1994), particularly when analysing fluctuations in population size. When monitoring yearly variation in salmon juvenile abundance by electric fishing, information on interannual variation in catchability is important. This variation might be caused by numerous factors, including sampling period (Niemelä et al. 2001), discharge, water temperature (Zalewski & Cowx 1990), juvenile density (Niemelä et al. 2000), and fish size (Borgstrøm & Skaala 1993).

Several studies have been made to evaluate the usefulness of one-pass electric fishing to estimate relative abundance of salmonid juveniles (Kruse et al. 1998, Mitro & Zale 2000). Even though variation in catchability is considerable for the single-pass method, the method is argued to give an index of juvenile density which is useful to monitor changes from year to year, i.e. relative density (Arnason et al. 2005). Therefore the single-pass method may be of great practical value. It also gives information on species richness, relative composition of year-classes, mean length and juvenile condition.

Atlantic salmon populations are mainly anadromous and inhabit a diversity of physical and biological environments. There is variability in freshwater habitat use and freshwater and seawater residence within the species (Klementsen et al. 2003). Growth of salmon parr is variable from one stock to another, which results in different ages of smolting, from 1+ to 4+ and occasionally up to 7+ years (Metcalfe et al. 1988, Antonsson & Gudjonsson 2002).

Density of salmon fry and parr has been estimated by electric fishing for many rivers across the distribution of Atlantic salmon. In northern salmon rivers such as the Teno River densities were highly variable between sites, but the mean density of fry was 24.5 100 m^{-2} and 17.9 100 m^{-2} for parr (Niemelä et al. 1999), and in the Alta River the mean density of parr was 12.4 in the lower part of the river and up to 36.5 parr 100 m^{-2} in the upper part (Saksgård et al. 1992). Estimated inter-stage survival seems to be highly variable from year to year, as for Atlantic salmon in Catamaran Brook, New Brunswick, where the range of survival (%) was 14.0-74.7 (average 33.3) for age 0+ to 1+ and 25.5-47.7 (average 33.5) for age 1+ to 2+ (Cunjak & Therrien 1998).

The aim of this study was to investigate long-term data sets of juvenile salmon abundance, which were collected using single-pass electric fishing, and how this method reflected the status of juvenile stocks. Long-term data were analysed to compare differences in relative density, mean length and relative biomass among four regions of Iceland. Secondly, long-term data sets were used to estimate mortality rate between years. It was hypothesised that mean length, relative density and biomass were significantly higher in the south-western (SW, W) than the north-eastern (NW, NE) part of Iceland, but that there would be less difference in between the south-western regions and in between the north-eastern regions. It was expected that mortality rate was lowest in the SW region and would increase clockwise around the regions from SW to NE.

MATERIALS AND METHODS

The study was carried out in 11 river catchments in four regions of Iceland: south-west (SW), west (W), north-west (NW) and north-east (NE) (Figure 1). There are major climatic differences between the NW/NE and W/SW regions due to the cold, low-salinity sea current coming from the north and the warm higher-salinity current coming from the south (Stefansson & Olafsson 1991). This results in relatively mild weather in the W/SW regions but more variable climatic conditions in the NW/NE regions. There are minor but clear differences between these two northern and two western regions due to landscape, bedrock and climatic factors (Einarsson 1984, Gudjonsson

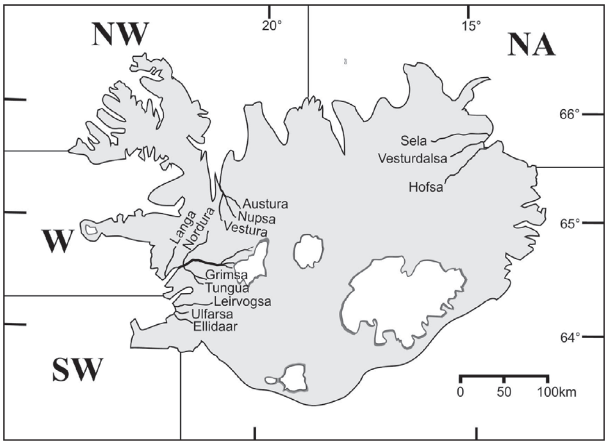

Figure 1. Map of Iceland showing locations of the rivers where juveniles of Atlantic salmon were sampled and the four geographical regions where the main salmon rivers are located.

1990). Two or three rivers were chosen to represent each of the four regions where the main salmon rivers are to be found (Figure 1). All the rivers are predominantly direct runoff rivers with similar characteristics as to chemistry and production except the River Ellidaar, which is a spring-fed river originating in young and permeable bedrock (Gudjonsson 1990).

Electric fishing was carried out using a single anode (18 cm diameter anode ring) with an output of 300 V DC and 0.5 A. Each sampling area was measured (length x width). Fish caught in each sample were anaesthetised (with MS-222), identified as to species and fork length (± 0.1 cm) and wet weights (± 0.1 g) measured. Scale and otolith samples were taken from 6-15 fish from each site to determine age structure. Age structure data were then used along with the length frequency distributions to separate age classes. All fish other than those sampled for age structure were released back into the area of capture.

The electric fishing was always carried out from late August to early September when water velocity is relatively low and the temperature is stable. Sample sites were in most cases located between natural barriers due to coarseness of the riverbed substrate and different velocities. Both were done to reduce variability in external factors that are known to affect the catchability (Zalewski & Cowx 1990). The time span of the series in each river ranged from 10 to 22 years, ending in 2001. The size of the sites sampled ranged from 100 m^2 to 600 m^2 and the sites in each river numbered from 8-12 but remained constant between years. In all cases relative density was defined as the number per 100 m^{-2} of juveniles caught by the single-pass electric fishing method.

To estimate the mortality rate between years within a cohort the relationship between the estimated relative densities of 1+ parr in the year n (N_1) were used and the estimated relative densities of the same cohort as 2+ parr in the year n+1 (N_2). Mortality rate was also calculated for 2+ (N_2) to 3+ (N_3) parr in the NE region where average smolt age was approximately one year higher than in the southern regions, and thus no emigration because of smolting could be assumed. With no immigration or emigration on the sample sites the survival is (N_2/N_1) and mortality M (%) = 1- (N_2/N_1)x100 (Robson & Regier 1968). Mean mortality was calculated for each river. If density estimates for the 1+ were very low <0.5 fish 100 m^{-2} the value was excluded. Such a low estimate for 1+ was only observed in the NE region where in some years 1+ parr are extremely small due to cold summers and/or late emergence of 0+ the year before, which results in low capture probability of the youngest juveniles during these years.

The averages for all (both) rivers in each region were calculated for relative density, mean length and relative biomass as dependent factors. ANOVA tests were used to compare these factors among the four regions. The Bonferroni pairwise multiple comparisons test was then used to further analyse the difference between each pair of means for the same factors.

Table 1. Mean survival of salmon juveniles (S), Standard error (s.e.) of S, percentage mortality (M%) and number of years (N), with data from eleven rivers in western and northern Iceland.

Name of river	N	S	s.e. of S	M, % age 1+/2+	M, % age 2+/3+
Elliðaár	16	0.683	0.101	31.7	
Leirvogsá	16	0.425	0.078	57.5	
Langá	15	0.778	0.086	22.2	
Tunguá	10	0.658	0.127	34.2	
Norðurá	13	0.831	0.092	16.9	
Vesturá	15	0.823	0.081	17.7	
Austurá	13	0.898	0.222	10.2	
Núpsá	15	0.785	0.132	21.5	
Hofsá	17	1.010	0.162	-1.0	23.4
Selá	17	0.880	0.099	12.0	41.0
Vesturdalsá	17	0.924	0.121	7.6	18.3

Table 2. Mean length L (cm) at age of salmon juveniles with 95% confidence interval (+/-) from the four regions: south-west (SW), west (W), north-west (NW) and north-east (NE) Iceland. The increase in mean length between year-classes is represented as ΔL (cm).

	Regions											
	SW			W			NW			NE		
Age\Length	L	+/-	ΔL	L	+/-	ΔL	L	+/-	ΔL	L	+/-	ΔL
0+	4.38	0.09		3.67	0.08		4.02	0.10		3.66	0.07	
			2.72			2.38			2.99			2.32
1+	7.11	0.11		6.05	0.11		7.01	0.10		5.98	0.09	
			2.31			2.18			2.18			2.15
2+	9.41	0.11		8.28	0.14		9.19	0.11		8.13	0.10	

Table 3. The main results of the analyses of variance among regions of annual mean length, mean relative density and mean relative biomass for 1+ and 2+ salmon parr. Salmon parr were sampled annually for 10-22 years by electric fishing in eleven rivers in four regions in Iceland.

	Age-class			
	One-year-old		Two-year-old	
	F	P-value	F	P-value
Mean length	25.6	<0.001	19.6	<0.001
Mean density	19.5	<0.001	10.4	<0.001
Mean biomass	22.5	<0.001	12.2	<0.001

RESULTS

Mean mortality rate (M%) between N_1 and N_2 varied from 8% to 58% in the 11 rivers analysed with the exception of the River Hofsá in NE Iceland where the mean mortality rate was –1% (Table 1). The estimated mortality rate (M%) between N_2 and N_3 for the NE region turned out to be 23.4%, 41.0% and 18.3% for the rivers Hofsá, Selá and Vesturdalsá, respectively.

The relative density of salmon age 0+, 1+ and 2+ varied markedly between geographical zones in Iceland (Figure 2). The density of age 0+ and 1+ groups was high in SW and W

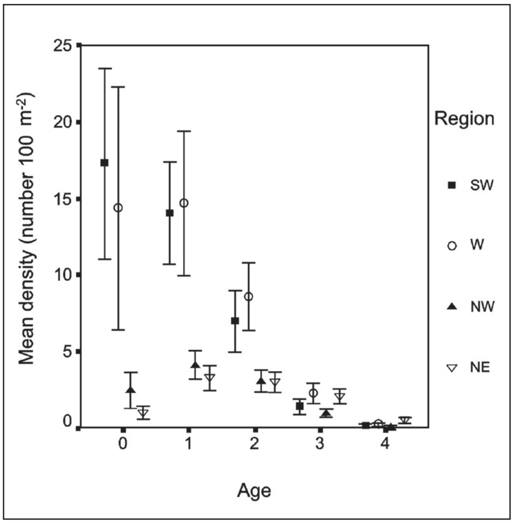

Figure 2. Mean relative density by age of Atlantic salmon juveniles in the study rivers. Data from rivers in the same the region are pooled. The regions are: south-west (SW), west (W), north-west (NW) and north-east (NE) Iceland.

Iceland, but declined rapidly between 1+/2+ and 2+/3+ (Figure 2). In NW and NE Iceland the 0+ group was poorly represented in the first year. The number increased between 0+ and 1+ and declined slowly after that and a substantial number of parr reached age 3+ and 4+ (Figure 2). The proportion of age 0+ and 1+ juveniles in relation to the total number of juveniles was highest in SW Iceland but declined clockwise from SW to NE. In the NE age 2+ and older constituted 85% of the biomass compared to 54% in SW Iceland (Figure 3). This pattern was associated with a higher number and biomass of age 0+ and 1+ fish per square unit in the SW and W regions compared to the same age in the NW and NE regions. The growth from age 0+ to 1+ was highest in the NW and SW regions (Table 2).

No significant difference was found in mean length, mean relative density and mean relative biomass among rivers within each region, except for one river in the SW, i.e. the Tunguá. To test for regional differences for these variables the data from within each region were pooled and significant differences were observed among fish from all the four regions for age 1+ and 2+ (Table 3). The Bonferroni pairwise comparison showed a significantly higher mean length in the SW and NW regions compared to the W and NE, but both relative density and biomass were significantly higher in the SW and W regions compared to the NW and NE. The same pattern was seen for both 2+ parr (Table 4) and 1+ parr.

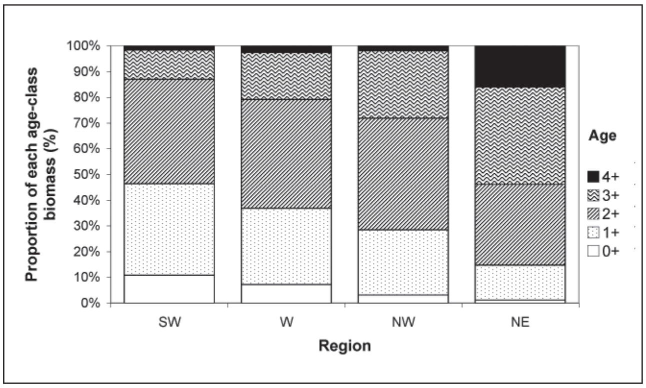

Figure 3. Proportion of relative biomass for each age-class by region. The regions are: south-west (SW), west (W), north-west (NW) and north-east (NE) Iceland.

DISCUSSION

The estimated mortality rate from N_1 to N_2 was highest in the SW region and decreased clockwise from the SW region to the NE region. This regional difference in mortality rate was opposite to what was expected. The more extreme climate in the NE and NW regions compared to the SW and W would in general be expected to result in a higher mortality rate. The lower mean length of juveniles in the NE might affect the catchability of the 1+ year class resulting in underestimation of density. This might lead to a lower mortality estimate from N_1 to N_2, since smaller fish are in general considered more difficult to catch by electric fishing (Bohlin

Table 4. Bonferroni pairwise test of mean length, mean relative density and mean relative biomass between geographical regions for 2+ salmon parr. The regions are: south-west (SW), west (W), north-west (NW) and north-east (NE) Iceland.

	SW	W	NW
Mean length			
W	1.20*		
NW	0.22^{ns}	-0.97*	
NE	1.28*	0.08^{ns}	1.06*
Relative density			
W	-0.91^{ns}		
NW	4.00*	4.91*	
NE	4.04*	4.95*	0.05^{ns}
Relative biomass			
W	6.16^{ns}		
NW	40.03*	33.87*	
NE	47.52*	41.36*	7.49^{ns}

& Sundström 1977). Clearly this was seen in the case of the River Hofsá when the value of M was a negative figure, which can chiefly be explained by a low catchability and low density estimate of 1+ parr in some years (mainly 3 out of 17 years in the case of the Hofsá) and that affect the average mortality rate of the whole period. Density of 1+ parr could be underestimated in years with late emergence and/or low growth rate, which consequently delay the spread to available nursery habitat. The estimate of the mortality rate between N_2 and N_3 in the NE region supports this conclusion. In that case the mortality rate was considerable higher than for N_1/N_2 for the NE but in harmony with the results from other regions for the N_1/N_2 mortality rate.

Winter conditions are highly variable over the geographical zone of distribution of Atlantic salmon. It is suggested that many physical and chemical conditions of the winter environment affect the survival of salmon juveniles (Cunjak et al. 1998). The mortality rate of Atlantic salmon fry has also been connected to their size (Good et al. 2001). In Iceland there is a great variation in the time of 0+ emergence in the rivers due to both annual and regional differences in climate, which are more extreme in the northern part of the country (Antonsson 1998). In the NW and especially in NE Iceland densities of 0+ salmon are estimated as low even in autumn at the end of the growing season due to small size and less probability of capture. The low estimate of 1+ parr in the NE region was probably the consequence of late emergence of 0+ the year before and/or unfavourable environmental factors in the growing season of 1+ parr during these particular years.

Data from long-term electric fishing studies show considerable variation in the population dynamics of juvenile salmon between geographical zones. Comparison among all the regions showed a significant difference in mean length, relative density and biomass, which was consistent with the hypotheses put forward in the introduction. When thoroughly tested (by the Bonferroni test) between each of the regions, the relative density and biomass were similar in the south-western (SW, W) regions and also in the north-eastern (NW, NE) regions, but there were significant differences between these two parts of the country. This result was in harmony with our hypotheses. It might be concluded that this difference is due to the influence of different environmental factors such as climatic conditions. Air and water temperature are more variable in the northern regions than in the southern regions and the same is true of physical factors at sea, such as salinity and temperature (Einarsson 1984, Stefansson & Olafsson 1991, Antonsson et al. 1996). Mean length, on the other hand, was unexpectedly similar in the SW and NW regions and also in the W and NE regions as it had been postulated that mean length would follow the same pattern as density and biomass. However, the greatest difference was still between the SW and NE regions, as it was for all the factors. There is no obvious explanation for this finding, but it should be kept in mind that growth rate is dependent on many factors such as food supply, competition (density) and other physiological and environmental factors.

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