Examensarbete
i ämnet biologi

Linking habitat characteristics and juvenile density to quantify *Salmo salar* & *Salmo trutta* smolt production in River Sävarån, Northern Sweden

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Contents

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Abstract

Even though the European Union has set up goals for rivers that support wild salmon to reach a production that is 50% of the MAXIMUM natural potential, there is a general lack of knowledge about the production capacity of salmonids in Sweden. To estimate the production of salmon and sea trout in the Sävarån river, I combined habitat mapping with available electro-fishing data. Additionally the smolt run was enumerated (with screw-traps) and radio-tracking of migrating spawners was performed.

In the river's main branch I found 51 ha potential spawning and nursery habitats. With present juvenile densities, these areas should be able to produce 1300-7580 salmon smolt and 635-3544 trout smolt, in agreement with screw-trap data in the years 2005-2007. A hypothetical maximum production of c. 18400 salmon smolt was also calculated. Telemetry showed that at the time of spawning the radio-tagged adult fish were situated in or close to potential spawning areas that were defined during the habitat mapping.

Keywords:
Mapping, Flow, Substratum, Electro-fishing, Parr, Radio-telemetry, Spawning

Svensk sammanfattning

Beräkning av laxens och öringens smoltproduktion genom habitat-tillgång och elfiske-täthet av juveniler i Sävarån, norra Sverige.

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Trotts att EU satt upp ett mål (Salmon Action Plan, SAP) där naturligt laxförande vattendrag skall ha nått en produktion som motsvarar 50 % av den MAXIMALA naturliga föryngringen, saknas i Sverige generell kännedom om den faktiska produktionen för lax och havsöring i åar och älvar. I ett försök att utreda just detta, har det i Sävarån gjorts en habitatkartering som sammanlänkats med tillgängligt elfiskedata. Samtidigt utfördes numrering av utvandrande smolt och radiotelemetristudier av lekvandrande vuxna fiskar.

Den totala arean av potentiella lek- och uppväxtområden i huvudfåran var 51 ha. Vid rådande elfisketäthet av stirr bör dessa ytor kunna producera 1300-7580 lax- och 635-3544 öringsmolt, denna uppskattning överensstämde i stort med skattningar gjorda med smoltfälla under åren 2005-2007. En förmodad maximal produktion skattades till ca 18400 lax smolt. Telemetri studier visade att under tiden för lek var radiomärkta vuxna fiskar positionerade i eller nära de potentiella lekområden som hittats under habitatkarteringen.

Introduction

Wild populations of Atlantic salmon (*Salmo salar* L.) and sea trout (*Salmo trutta* L.) in the Baltic Sea area have been severely diminished due to over fishing, hydropower, logging, pollution, diseases (M74) etc. (McKinnell 1998, Rivinoja 2005, Östergren 2006, Palm 2007). Consequently the number of rivers running into the Gulf of Bothnia that still hold naturally reproducing salmon populations have been reduced from 45-50 to only 13 (Romakkaniemi *et al.* 2003, Uusitalo *et al*. 2005), which has led to the situation today in which wild salmon populations are threatened. The situation for sea trout in this area seems even worse (Kallio-Nyberg *et al.* 2003, ICES 2008). Historically sea trout was common in most streams, while in Sweden today they are only found in 51 watercourses running into the Gulf of Bothnia, and at the same time the status of these populations are highly uncertain (ICES 2008).

In 1997 the International Baltic Sea Fishery Commission (IBSFC) established the Salmon Action Plan (SAP) with the intention to preserve the wild salmon stocks in the Baltic sea area. A goal for 2010 of ensuring at least 50% of the maximum natural smolt production capacity was set for rivers that still hold wild populations (Anonymous 1999, Uusitalo *et al*. 2005). This has resulted in various management programmes to enhance the salmonid populations. Many of the rivers with natural reproduction have been stocked with hatchery reared juveniles and efforts to restore river habitats and renew migration routes for fish have been carried out. One such case is River Sävarån in northern Sweden, where substantial stockings of salmon and sea trout (Östergren 2006), dam removal projects and restoration of river habitats (Norberg & Ahlström 2007), have been carried out. Since 1989 the salmon and trout populations in River Sävarån have been monitored by electro-fishing (Rivinoja & Carlsson 2008) and in 2005-2007 enumeration of out migrating smolts by screw-traps have been performed (Lundqvist *et al.* 2008b). Still relatively little is known about the production capacity of salmon and trout in northern rivers, particularly for the Scandinavian ones, and to asses this issue in a proper way, new reliable data needs to be collected. In this work, this was done by combining available electro-fishing and smolt data, with additional novel data regarding habitat mappings and radio-tracking of spawning migrating adults. The overall aim was to determine the current production of salmon and sea trout in River Sävarån and to estimate the maximum possible production of smolts. The following issues were addressed:

- Mapping of potential production areas for salmon and sea trout. This included assessment of available areas of various habitat qualities required for spawning and nursery.
- Estimation of juvenile fish densities and smolt production by available electro-fishing data.
- Enumeration of the smolt run by screw-trap data.
- Tracking of spawning migration and site selection of adult salmon and sea trout.

Life history of anadromous Salmon and brown trout

The anadromous Atlantic salmon and brown trout, hereafter sea trout, migrate from oceans into fresh waters for spawning. In Scandinavia the returning adults ascend the rivers throughout the summer and finally spawn in late autumn (Klemetsen *et al.* 2003). While sea trout often prefer to spawn in tributaries, the salmon generally spawn in the main stem of the rivers in areas that generally hold relatively fast flowing water and coarse gravel (Armstrong *et al.* 2003). After spawning the surviving salmon and sea trout (defined as kelts) migrate seaward. This can take place both shortly after the spawning in the autumn, while fish may also overwinter in the rivers and migrate seaward the following spring (Niemelä *et al.* 2000, Östergren & Rivinoja 2008). In spring following spawning, the eggs hatch and fry emerge from the gravel beds (Fleming 1996). Juveniles, named parr, may thereafter remain in freshwater from one to several years until they undergo smoltification that initiates seaward migration. In the Baltic Sea, the fish spend from one to five years, depending on species and environment, before they home their natal streams for spawning (Klemetsen *et al.* 2003).

Material and Methods

Study area

The River Sävarån, a northern Swedish forest river, enters the Gulf of Bothnia at N63°54’ 38.6”, E20°33’ 56.5” (Figure 1). The river is about 142 km long, with a main catchment area of 1.161 km^2 (c. 6.5 % covered by lakes), annual flow varies between 1-100 m^3s^{-1} with a mean of about 12 m^3s^{-1} (Lundqvist *et al.* 2008b). Historically the river has (like many Swedish rivers) been used for timber floating, which together with dam constructions are well known to have had negative effects on salmonid populations (Nilsson *et al.* 2005). In 1998 a fish ladder was built at the waterfall Krokbäcksfallet, 52 km upstream of the river mouth, previously acting as a partial barrier for upstream migrating fish; however since the ladder construction the numbers of fish passing this area between June to September have been recorded. From year 2000 to 2007, the annual amount of salmon has varied from 0 to 96, while 0-49 sea trout have been registered (Table 1). The river has an estimated production capacity of 4000 salmon smolt per year (Anonymous 1999, Uusitalo *et al.* 2005) and a reproduction area that of about 20 ha (Anonymous 1999).

Since 1989 the River Sävarån has been stocked with juvenile salmon and trout originating from at least three of the surrounding rivers (Ume-Vindelälven, Öreälven and Byskeälven), resulting in total releases of around 850 000 salmon and 56 000 sea trout. Genetic analyses of the out migrating smolts indicate that the salmon at the river show introgression from the latest relatively massive stockings of salmon from the River Byskeälven strain, while no clear patterns have been found for trout (Lundqvist *et al.* 2008b).

In 2007 the temperature in Rivers Sävarån (measured with Onset StowAway-TidBit loggers, located 15 km, respectively 55 km upstream of the river mouth) showed a typical pattern for rivers in this region. The temperature increased steadily from about 15°C from mid June to about 20 °C in August. In the autumn temperatures gradually dropped, and 9-10 °C was noted above the fish ladder. During late September 7-8 °C was measured lasting during the first week of October, after which the temperatures decreased rapidly to about 4 °C in mid October. The flow during the study period showed the general pattern of relatively low stable summer flows, with flow increasing because of heavy rain for one week in mid September and thereafter stabilizing at normal levels.

Table 1. Annual counts of fish passing the ladder at the waterfall Krokbäcksfallet.

Year	Number of fish	Average length (cm)	Salmon	Sea trout
2000	120	85	96	24
2001	52	73	34	18
2002	24	78	18	6
2003	0	-	-	-
2004	78	65	29	49
2005	1	70	1	
2006	17	Salmon=77, Trout=59	4	13
2007	63	Salmon=88, Trout=65	16	47

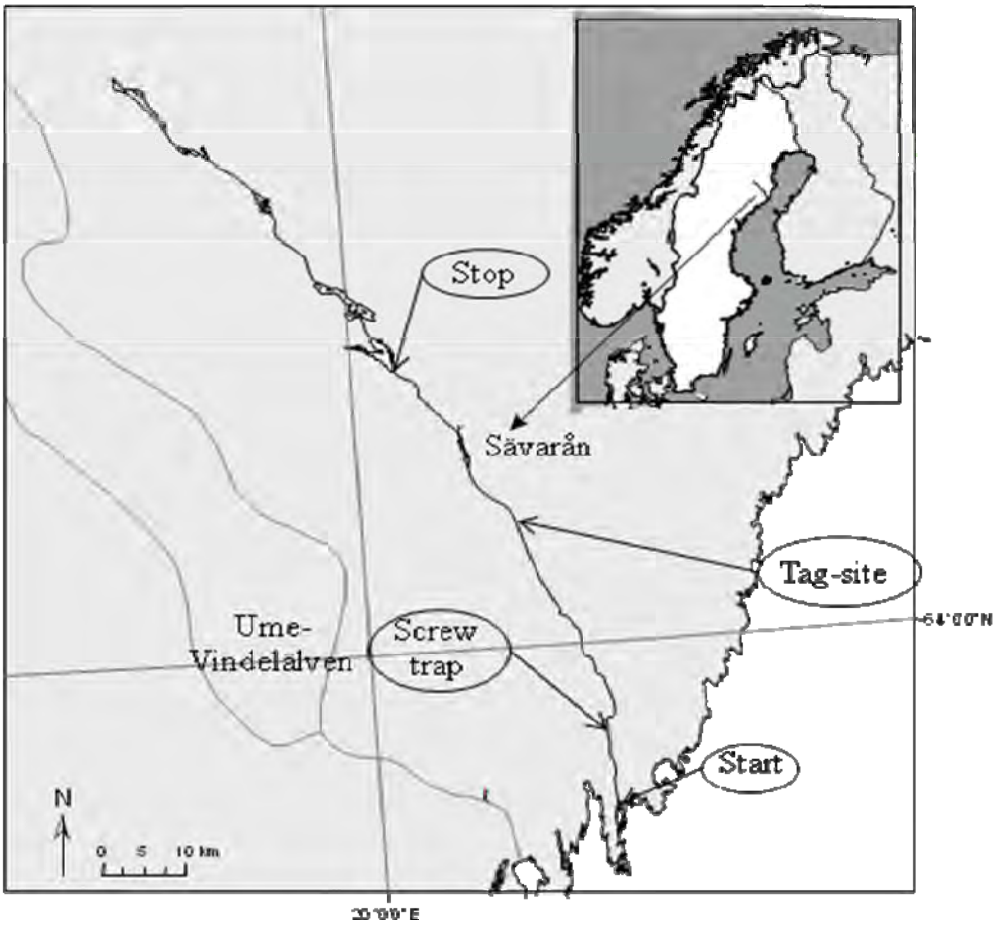


Figure 1. Map showing geographical position of River Sävarån. Sites of interest also shown are the start and stop of the habitat mapping, tagging site and the location of the screw-trap.

Habitat mapping

The mapping of habitat characteristics in the main stem of River Sävarån generally followed the method described by Halldén *et al.* (2002). Initially, aerial photographs (obtained from the National Land Survey of Sweden, Lantmäteriet) that covered the river were studied by using the software ArcGis 9.2. The aim was to determine various stream sections of the river and to facilitate the subsequent habitat mapping survey in the field. During the field work in June-October 2007 the whole river stretch, a total river distance of approximately 85 km, ranging from the slow flowing estuarine areas (10 km from the river mouth), up to Lake Lillsävarträsket (c. 5 km long and 1.4 km wide, c. 705 ha) was mapped by walking along or in the river. Various river sections, representing different habitat types (e.g. pool/riffle areas) were defined and data stored in a GPS (Garmin 60Cs) with an appropriate map (Friluftskartan PRO). Photographs were taken on every stretch and at each section multiple measurements of river width (OPTi-LOGIC 600XL, accuracy of ± 0.9 m) and depth (wading stick < 2.0 m, accuracy of ± 0.1 m) took place. The dominant features such as bottom substrate type, vegetation, water velocity, human disturbance (such as remnants from the logging era) and restoration efforts for each specific river section were estimated visually. The cover area of dominant substrates were classified as either clay (<0.02 mm), sand (0.02-2 mm), gravel (2-20 mm), pebble/cobble (20-200 mm), boulder (>200 mm) or rock (>4000 mm). Stream velocities were classified into following groups: slow flowing (<0.2 m/s, deep and slow-flowing water), slow riffle (no turbulence, smooth bottom and intermediately deep water), fast riffle (turbulent water) and rapid (>0.7 m/s, highly turbulent water). If several types of bottom substrates and water velocity groups were present within a section, their occurrence was described as a percentage of the total section area (a refinement of the method of Halldén *et al.* 2002).

In addition to the classifications of physical parameters, the suitability for salmonids at each reach was visually judged with a focus on bottom substrate composition and water velocity. Following Halldén *et al.* (2002), these were grouped into three apparent habitat types (Table 2), with definitions also corresponding to Crisp (2000) as suitable habitats for salmon and trout. The three groups; 1) Spawning ground, 2) Juvenile nursery habitat, were treated as equally important regarding their potential as suitable for different life stages for salmon and/or sea trout. Holding sites for adults (3) were noted but not emphasised as much as the other two.

Electro-fishing

Annual electro-fishing data on juvenile densities of salmon and trout in River Sävarån was gained from Rivinoja & Carlsson (2008). The electro-fishing methods followed the Swedish standard (Degerman & Sers 2001) and have been carried out in Sävarån since 1989 on sites that were presumed to be suitable for juvenile salmonids, all connected to sections judged in the later habitat mapping to be at least potentially suitable habitats. All caught fish have been measured to the nearest mm to permit separation of various year-classes (Rivinoja & Carlsson 2008). Data for the years when electro-fishing was not performed were linearly interpolated between the mean densities of juveniles registered the year before and the year after. Furthermore, supplementary analyses of data from Rivinoja & Carlsson (2008) were performed to be able to compare River Sävarån to other rivers in the same region.

Table 2. Classification of habitat suitability for spawning, juvenile nursery and adult holding (Halldén *et al.* 2002).

Habitat type	Class 0	Class 1	Class 2	Class 3
Spawning ground (1)	No possibility for spawning	No apparent spawning grounds, appropriate water velocity	Adequate spawning possibilities (not optimal)	Suitable with optimal spawning conditions
Juvenile nursery (2)	Not suitable	Possible, not satisfactory	Reasonably good, not optimal	Suitable with optimal nursery conditions
Adult holding (3)	None	Possibility for solitary fish	Fairly suitable for adults	Good conditions for adult fish

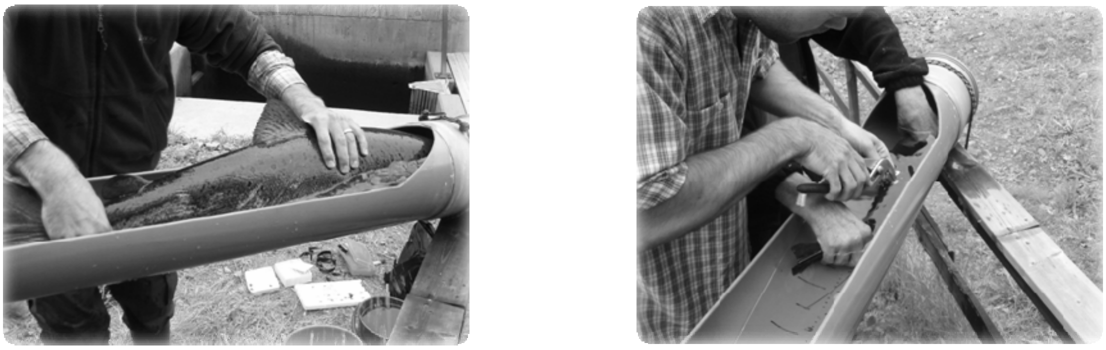
Tagging, tracking migration and genetic identification of spawning migrants

Spawning migrating wild Atlantic salmon and sea trout were trapped and radio-tagged in June-August 2007 at the last pool of the fish ladder in Krokbäcksfallet (52 km from the mouth of River Sävarån). The tagging of salmon with gastric transmitters (ATS-F1820, mass 8 g in air and operational ca. 200 days) followed Rivinoja *et al.* (2006), while sea trout were tagged externally with activity transmitters (ATS-F2120, mass of 15 g in air and battery life of c. 400 days) in accordance with Økland *et al.* (2001). These sensor transmitters are activated by fish motion, thus enabling monitoring of swimming behaviour and spawning activity (Östergren 2006). Handling of fish took place in a live-box cradle with ambient river water (Picture 1), where also lengths of fish were measured (cm). For each salmon, the sex was determined and a small sample taken from the anal fin for genetic characterization based on 10 DNA microsatellite markers (described by Östergren 2006). All fish handling (except of the tagging) followed the standard procedure at the ladder, which means that fish were netted from the last enclosed pool at the ladder exit, hand measured and thereafter carried 50-100 m upstream before released back into the river. In total twelve salmon ranging from 74-108 cm in length, and four sea trout (55-85 cm) were radio-tagged (Table 3), which accounted for 25 percent of the total run of both salmon and sea trout registered at the ladder in 2007.

After releases, the individual migration patterns of radio-tagged fish were followed by manual (ATS R2100 with 4-element Yagi-antennas) and archival radio-tracking units (LOTEK SRX_400, 4 and 8-element Yagi-antennas) as described by Rivinoja *et al.* (2001) and Lundqvist *et al.* (2008a). The archival unit was placed 1.5 km upstream of the tagging site at a potential spawning area. Weekly tracking from car and by foot took place until the first week of October (the spawning period) and after this manual tracking took place monthly. The specific habitats where tracked fish had been found were later analysed in the ArcGis map that was created in the habitat survey.

Table 3. Summary data regarding salmon and sea trout tagged at the fish ladder.

	Salmon	**Sea trout**
Date of tagging	12/6-25/7	25/6-12/8
Size (cm)	93 (74-108)	67 (55-85)
Total	12 (10 female, 2 male)	4 (3 female, 1 male)



Picture 1. Length measurement of salmon and tagging of sea trout in the live-box cradle at the ladder.

Calculation of smolt production and enumerations in screw-traps

Estimation of salmon and trout smolt production in River Sävarån was possible by combining data from the habitat survey with the data from the annual electro-fishing. These estimated numbers were later compared to data from the smolt enumerations from screw-traps.

Firstly the mapped areas that corresponded with electro-fishing sites were examined and thereafter all similar habitat quality classes were summed into unique groups representing suitability indexes for salmon and trout. Secondly the quantity of the smolt run (assuming smolts are 3-y old as indicated by Lundqvist *et al.* 2008b) was estimated by using survival rates for various age-classes of fish from fry to smolt with values based on averages obtained from Lundqvist *et al.* (2008a). The calculation steps and values are illustrated by Figure 2 and electro-fishing densities are shown in the Appendix (Table 1-2). To calculate the total numbers of fish in each year-class, the densities of fish (individuals of each year-class/m^2) were multiplied with all areas (m^2) classified as either potential or optimal (Table 4). These values were then used, by stepwise adapting various survival rates of fish from respective year-class, to calculate the contribution to the smolt run the following years, e.g. fish caught at electro-fishing at age; 0+ = 0.5*(0.8*0.5)*(0.8*0.5) and 1+ = 0,5*(0.8*0.5). Assumed that all existing potential habitats (Table 4) were used for spawning and nursery, the smolt run defined as "Maximum production" was estimated. In contrast to this, the smolt production incorporating only the optimal habitats assuming 100% utilization of juveniles at the areas was calculated, defined as "Minimum production". In the final step only the percentage of the electro-fishing sites that were found to be populated were used for calculations together with all potential habitats, defined as "Realized production" (Appendix, Table 1-2 columns 6-7). "Hypothetical maximum" salmon smolt production (100% of all potential habitats colonized by juveniles) was calculated by using densities of 20 age 0+, respectively 10 age > 0+ per 100 m^2 (values based on reasonably low maximums gained from studies in northern rivers, e.g. Johansen *et al*. 2005, Saltveit 2006, Rivinoja & Carlsson 2008).

From 2005 to 2007 migrating smolts was collected with one or two rotary-screw-traps (EG Solutions, Oregon, USA, operation described by Thedinga *et al.* 1994), placed 15 km upstream of the mouth of River Sävarån (details in Lundqvist *et al.* 2008b). The traps were located in relatively fast flowing water in the main steam and had V-shaped guidance fences in front of them to collect as many downstream-migrating fish as possible. The numbers of salmon and trout, their size (mm) and age were recorded. In addition mark-recapture studies using Carlin-tags were carried out and Seber-estimations used to calculate the number of migrating smolts (descriptions in Lundqvist *et al.* 2008b).

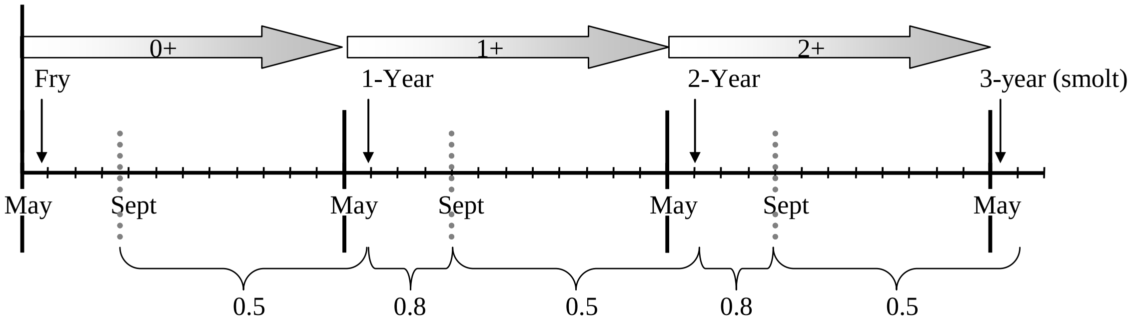


Figure 2. The calculation steps of fish in each year-class followed Rivinoja & Carlsson (2008) and assumed that most juveniles in River Sävarån smoltify at 3-year age as shown by Lundqvist et al. (2008b). The stroked lines indicate the periods of the annual electro-fishing in autumn. Predicted survival rates for juveniles of different ages are shown at the bottom with values based on averages from Lundqvist et al. (2008a).

Results

Habitat mapping

A total of about 21 km of the river stretch (24% of the total 85 km) were found to hold areas classified as potential habitats for salmon and trout (definitions in Table 2). In addition, two possible hindrances for upstream migrating fish were identified; one close to the town of Sävar consisting of a hydropower-station (12.5 km upstream of the coast) and another at the waterfall Krokbäcksfallet in the fish ladder area (52 km from the mouth).

In total, the mapped river stretch (202.4 ha) was classified into 179 separate sections (Table 4). The total amount of potential and optimal salmon and sea trout spawning and nursery areas was 51.3 ha (25.3%) and 13.7 ha (6.8%), respectively. The part made up by the Lake Ytterträsk/Botsmarksjön (an approximately 3.6 km long and 0.2-0.7 km wide section, 139 ha), was left out from the total area summation since these lentic waters were considered inadequate for salmon/sea trout spawning and nursery. The river section upstream of the waterfall Krokbäcksfallet had 21 ha of potential spawning and juvenile habitat (the distribution of habitats above and below the waterfall is summarized in Figure 2). Of these, 10.5 ha were found between the fish ladder and the Lake Ytterträsk/Botsmarksjön, while an additional 10.5 ha were found above the lake up to Lake Lillsävarträsket (where the mapping ended).

Table 4. The amount (ha) of various areas as suitable habitat for salmon and sea trout. The production of smolts was calculated from columns three and four, indicated by Potential areas (given classification values equal to or greater than 1:1) and Optimal areas (classes equal to or better than 2:2). Classification (column one) is given as a combination of spawning: nursery habitat suitability according to Table 2.

Classification	Total area (ha)	Potential areas (ha)	Optimal areas (ha)	% of total	N(#)
0:0	147.1	-	-	72.6	50
0:1	1.9	-	-	1.0	7
0:2	1.0	-	-	0.5	7
0:3	0.1	-	-	0.0	1
1:0	1.1	-	-	0.5	4
1:1	13.3	13.3	-	6.5	28
1:2	15.3	15.3	-	7.6	32
1:3	3.4	3.4	-	1.7	7
2:0	0.3	0.3	-	0.2	1
2:1	5.2	5.2	-	2.5	13
2:2	7.0	7.0	7.0	3.5	18
2:3	5.1	5.1	5.1	2.5	7
3:0	0.0	0.0	0.0	0.0	0
3:1	0.0	0.0	0.0	0.0	0
3:2	0.8	0.8	0.8	0.4	2
3:3	0.9	0.9	0.9	0.4	2
Total	**202.4**	**51.3**	**13.7**	**100**	**179**

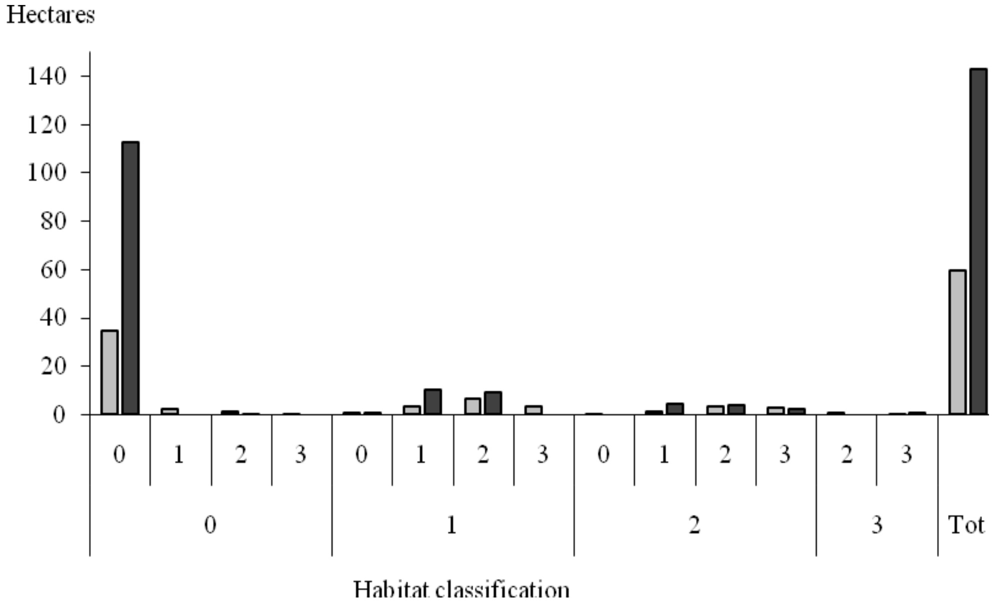


Figure 3. Distribution of spawning and nursery areas upstream (grey bars) and downstream (black bars) of the fish ladder (vertical axis, hectares). Classification of habitat suitability for spawning (minor tick mark type) and nursery (major tick mark type) for each transect is presented at the horizontal axis.

Electro-fishing

The densities of salmon and trout juveniles (Figure 4-5, Appendix Table 1-2) showed relatively large variations from 1989 to 2006 (salmon 0+/100 m^2 = 0.2-12.8 and >0+/100 m^2 = 0.9-16.9; trout 0+/100 m^2 = 0-3.9 and >0+/100 m^2 = 0.1-6.1. Even though the number of juvenile salmon has increased over the period, the trend lines have relatively low explanatory power (e.g. R^2 for 0+ = 0.37 and R^2 for >0+ = 0.49). For trout the densities are low and no changes over time in the population could be detected, with trend lines showing very low explanatory power (R^2 for 0+ = 0.05, R^2 for >0+ = 0.03). Additional data analyses indicated that the population growth of 0+ salmon in River Sävarån is weak when compared to the average trend of all neighbouring forest rivers, R^2 for 0+ = 0.84. Then again, these rivers also showed low densities of trout, low explanatory trends and no distinguishable population growth, R^2 for 0+ = 0.003, R^2 for >0+ = 0.1. During the years electro-fishing has been conducted in River Sävarån, salmon have been caught on 29-100% of the sites, while the corresponding number for trout is only 1-7% (Appendix, Table 1-2). No increases in proportion of utilized areas have been detected over the time period, although salmon of age >0+ were found in all sites in 2000-2004.

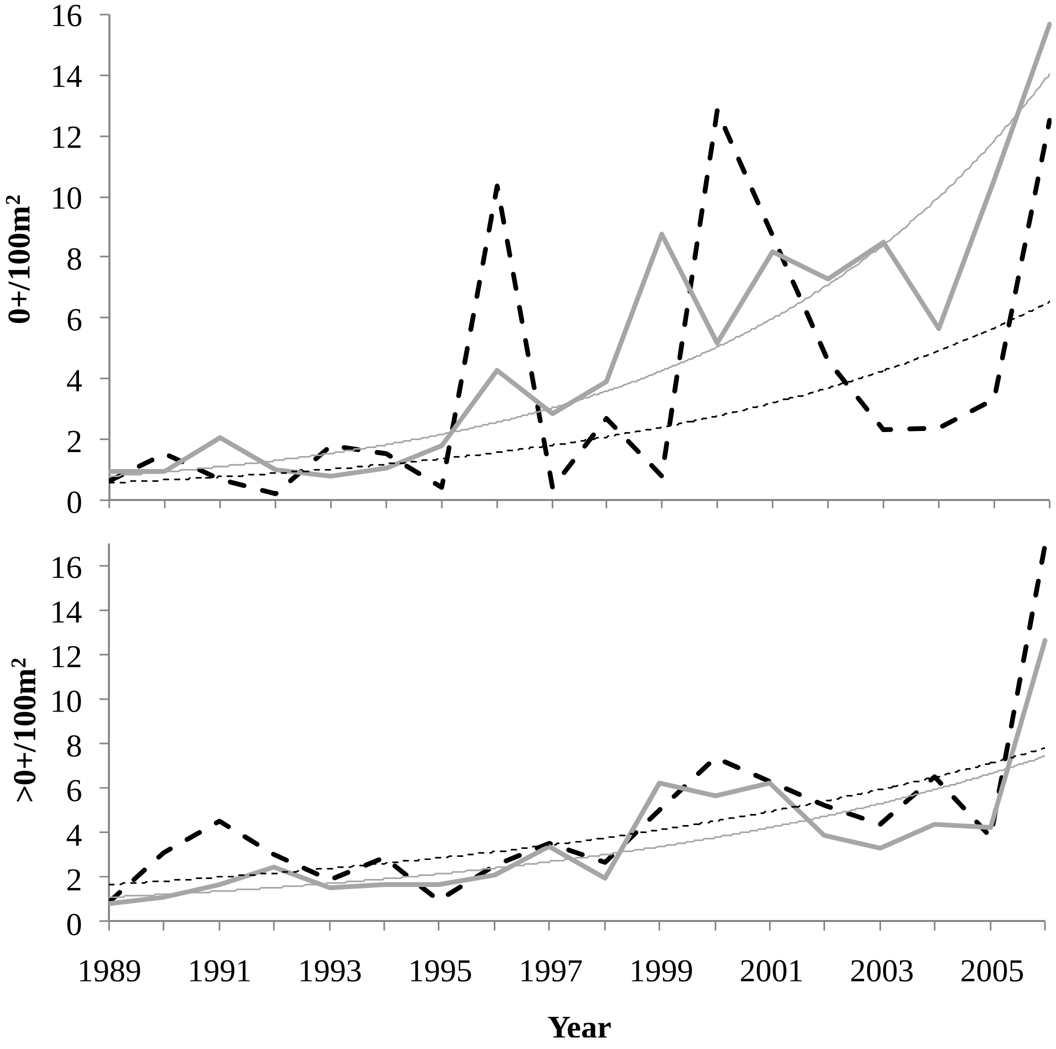


Figure 4. Salmon age 0+ (upper) and >0+ (lower) densities in River Sävarån (dotted lines) and mean densities (grey lines) for other rivers in the region. The trend lines (River Sävarån; dotted line, mean densities; grey lines) show population development from 1989 to 2006. No electro-fishing took place in 2001, so values were linearly interpolated as explained in the text.

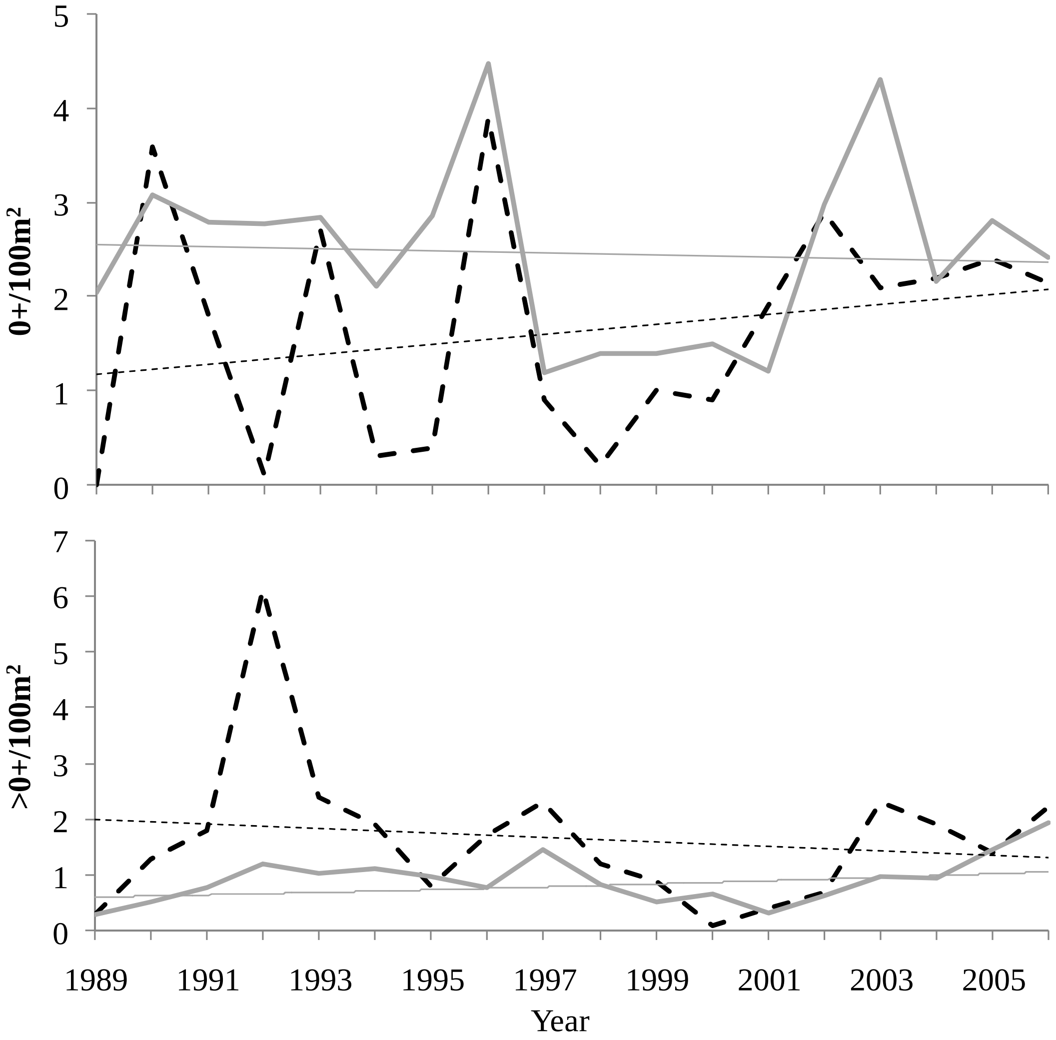


Figure 5. Trout age 0+ (upper) and >0+ (lower) densities in River Sävarån (dotted lines) and mean densities (grey lines) for other rivers in the region. The trend lines (River Sävarån; dotted lines, mean densities; grey lines) show population development from 1989 to 2006. Since no electro-fishing took place in 2001 and 2004, values are calculated as an average explained above.

Migration and genetics of spawning migrants

The general migration patterns for representative fish (n=4) are illustrated by Figure 6, this shows both the location of fish upstream and downstream of their tagging site in the ladder. In total, ten out of the twelve radio-tagged salmon (83%) fell back over the waterfall shortly after they were released close upstream of the fish ladder exit. Similarly one (represented by ID 4 in Figure 6) of the four trout moved downstream (25%). None of the fallbacks re-entered the ladder, however all except two salmon that continued downriver (9-11 km), remained relatively stationary over the spawning period at potential spawning areas in section 0-6 km downstream of the ladder (represented in Figure 6 by ID 2).

Of the fish that continued upriver (2 salmon, 3 trout; including ID 3 shown in Figure 6) a large variation in migration behaviour was noted. One of the trout remained stationary about 0.6 km upstream of the ladder, close to a potential spawning site, while remaining fish migrated to the area at the archival receiver (1.5 km upstream of the ladder) 2-20 days after tagging. One salmon (ID 1, Figure 6) spent 59 days at this river section before migrating to rapids 6 km upstream (optimal spawning area) where it remained for 14 days. A second salmon arrived at the same rapids 81 days post-tagging after spending 71 days at

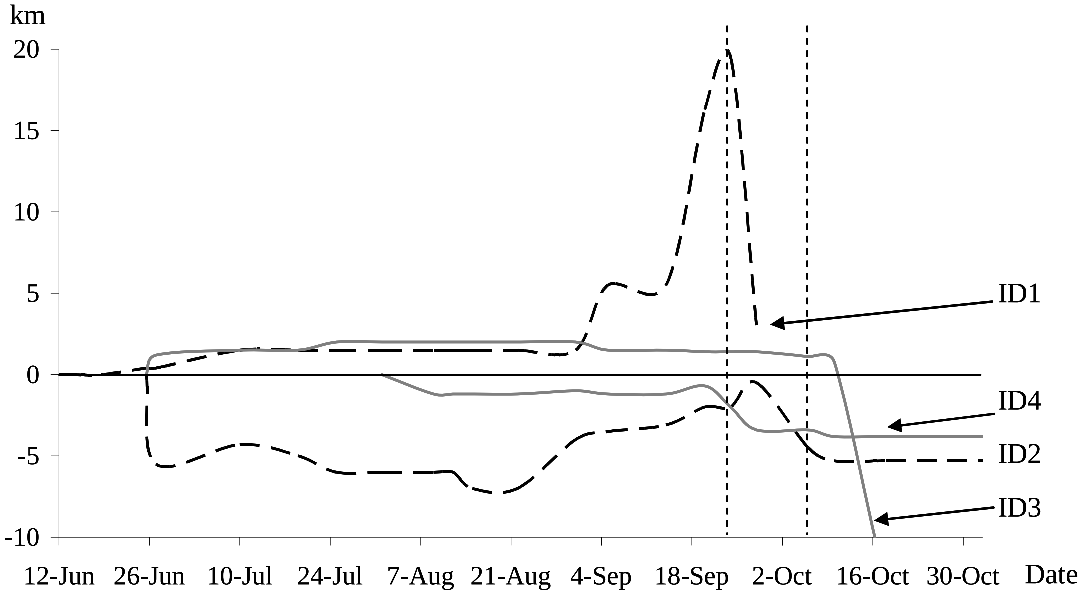


Figure 6. Migration patterns for two salmon (black dashed lines) and two sea trout (grey lines) in relation to the tagging-site (0 km, black horizontal line). Each species are represented by one fish upstream and one fish downstream of the ladder. The vertical dotted line indicates the spawning period. Horizontal axis shows tracking dates in 2007.

the area around the archival receiver. This fish stayed in the rapids over the spawning period and then went downstream. Maximum migrated distance (20 km upstream of the ladder to a potential spawning area) was reached by the earliest tagged salmon (ID 1) in late September after which it moved downstream. Two of the three trout above the ladder arrived at the area near the archival receiver area two days after tagging. One stayed at this area (classified as an optimal spawning site) over the spawning period, in total 50 days, while the other one continued upstream after two days at the same section.

Between the 28th of September and the 6th of October fish changed behaviour, and after showing only limited movements for some time, most fish started to move downstream. These changes, together with recorded pulse-rate intensity for one of the trout, were used to define the spawning period. One closely monitored sea trout, with data recorded at the archival receiver, clearly demonstrated increased activity around 08:00-09:00 at the 29th and 30th of September. During the spawning period all tagged fish (except two salmon which were presumed to have lost their tags) were located close to possible (potential or optimal) spawning sites. This included fish downriver of the ladder.

Two of the tagged salmon were found to differ considerably in their genetic background: in contrast to the others that with 88-98% probability belonged to the previously defined (Östergren 2006) River Sävarån strain (Appendix Table 4). The first tagged salmon (ID 1, Appendix Table 4) was descended from the River Byskeälven strain (92% probability), while the second (ID 10, Appendix Table 4) showed an inconclusive origin: a 59% chance of being descended from the Byskeälven strain and a 41% probability of being of River Sävarån strain.

Calculation of smolt production and enumerations in screw-traps

Assuming that that all present potential spawning and nursery areas are populated by fish, the combined habitat mapping and electro-fishing data estimated an annual salmon smolt production varies between 2000 to 11500 for the years 1992-2007, the defined “Maximum production” (Figure 7). The corresponding numbers of trout would be 500-7000 (Figure 7).

For the period 2005-2007 the “Maximum production” of smolt was predicted to between 4900-7500 for salmon and 2300-3500 for trout, numbers that are in agreement with the smolt enumerations in the screw-traps, 2320-5081 and 340-2518, for salmon and trout respectively (Figure 7 & Table 5).

Taking into account that juveniles are not caught at all specific electro-fishing sites, proportions varying from 29-100% for salmon and 1-7% for trout among years (Appendix, Table 1-2), the estimated number of smolts would decrease a similar amount. Calculating first with salmon found at potential habitats the “Realized production” of smolt would vary from 800-11500 and second for salmon utilising only optimal habitat, the defined annual “Minimum production” smolt production would be 200-3000 for 1992-2007. For trout, the relatively few areas where fish have been caught at electro-fishing, predicted 20-400 smolts for potential habitats “Realized production” (Figure 7) and 140-1900 smolts as a “Minimum production” (Figure 7) per year, for the time period. Yearly “Hypothetical maximum” salmon smolt production was estimated to about 18400, for the present potential areas in the main river stem.

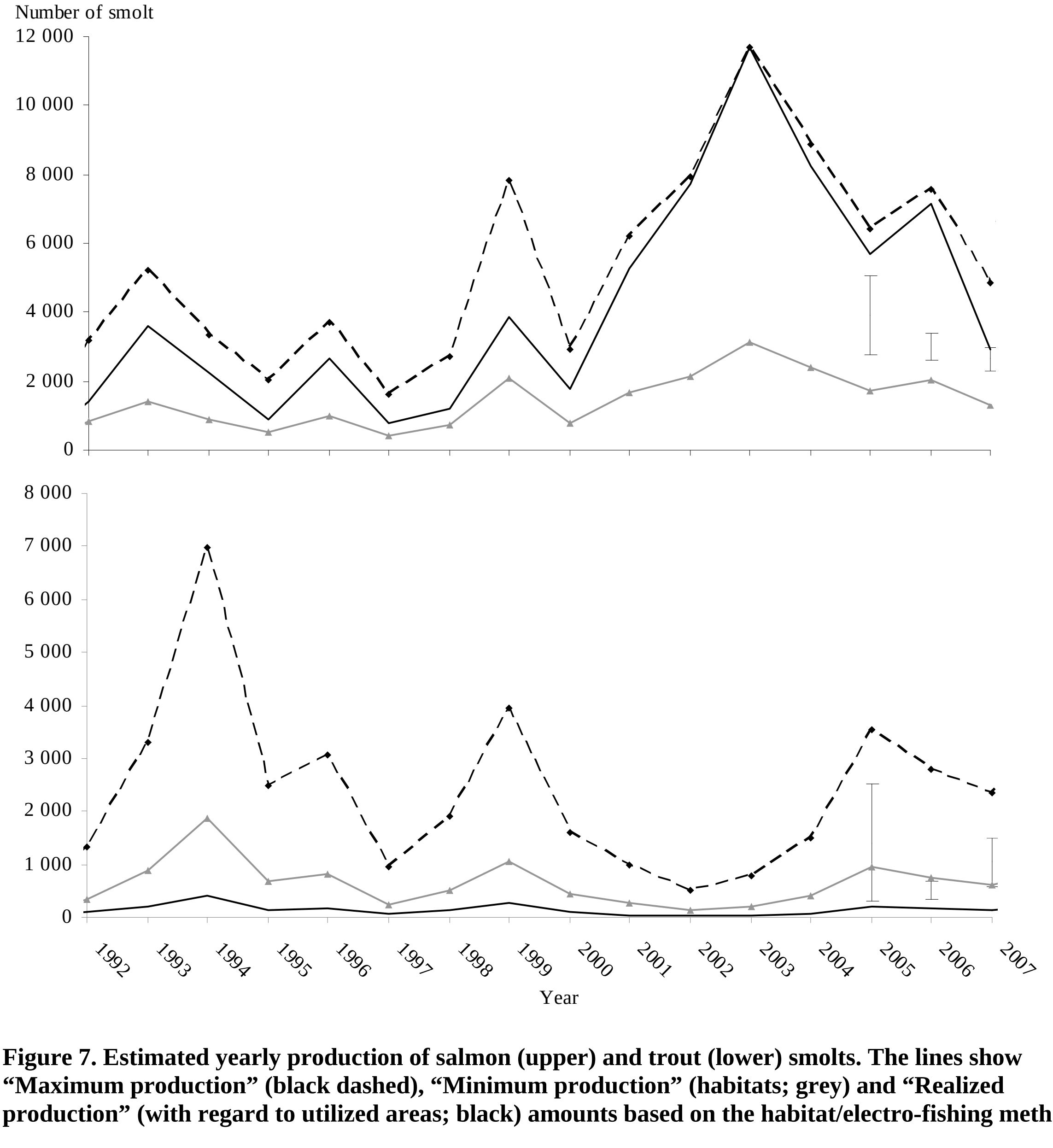


Figure 7. Estimated yearly production of salmon (upper) and trout (lower) smolts. The lines show “Maximum production” (black dashed), “Minimum production” (habitats; grey) and “Realized production” (with regard to utilized areas; black) amounts based on the habitat/electro-fishing method.

The min-max values (95% confidence intervals) from the screw-trap enumerations in 2005-2007 are indicated by black vertical lines.

Table 5. Estimated smolt production from the habitat/electro-fishing method when assumed that all optimal respectively potential habitats can hold juveniles. Smolt run enumerations from the screw-traps are given as min-max values based on 95% confidence intervals (data from Lundqvist *et al.* 2008b).

	Year	Habitat/Electro-fishing;		Screw-trap; min-max
		Realized production	Min - Max production	
Salmon	2005	5694	1710-6391	2783-5081
	2006	7165	2028-7580	2616-3407
	2007	2927	1300-4859	2320-2990
Sea trout	2005	201	948-3544	290-2518
	2006	186	751-2806	340-681
	2007	149	625-2335	590-1490

Discussion

The production of salmon smolts, estimated by combining the habitat mapping survey and electro-fishing data, generally matched the smolt run estimations by the screw-traps in 2005-2007 (as illustrated by Table 5). Nevertheless the “Realized production” of sea trout smolts estimated by the habitat/electro-fishing method, was lower than the screw-trap enumeration. In 2006 an additional discrepancy was noted for salmon when the habitat/electro fishing-method estimated more smolts than was predicted from the screw-traps. This might be caused by relatively high densities of juveniles caught at the few electro-fished sites in 2004, which could have caused an overestimation of the actual juvenile densities in the river. It is established that harsh winter conditions can reduce survival of juveniles (Huusko *et al* 2007) and that low flows can increase the losses of seaward migrating smolts (Rivinoja *et al.* 2007). Whether or not these factors acted in River Sävarån and caused low parr to smolt survival in 2005 and high losses took place in the smolt run 2006 is unknown. Since the mortality rate of smolts at the seaward migration in River Sävarån is unknown, the data was not adjusted for these losses. However the number of smolts (originating from reproduction areas 0-70 km upstream) passing the area at the screw-trap would be reduced, as elevated losses takes place at lentic areas (Olsson *et al.* 2001, Rivinoja *et al.* 2007). This could explain the somewhat higher salmon smolt estimations by the habitat/electro-fishing method than was calculated from the screw-trap.

The higher estimates for sea trout, defined as “Maximum production”, are explained by the fact that this calculation assumed that all potential main river areas were populated by juveniles. However, these production numbers are higher than the “Realized production” estimates and also show an overestimation when compared to the screw-trap data. In the main stem, trout juveniles were only found in relatively few of the electro-fished sites in contrast to salmon that were relatively common. Likewise the “Maximum production” and “Realized production” of salmon only show a moderate divergence. In combination with the low estimated “Realized production” all the above-mentioned facts strongly suggest that tributaries accounted for a majority of the sea trout production. Complementary data (ICES 2008) also demonstrated that the densities of trout parr were higher in the tributaries than in the main river (Appendix, Table 1 & 3). These results agree with previous statements, that sea trout often spawn in tributaries (Armstrong *et al.* 2003) and even if a proportion of the trout juveniles caught at the electro-fishing might belong to resident non migratory brown trout, the relatively higher densities in the tributaries highlight that these areas are important for sea trout rejuvenation in the River Sävarån system.

The “Hypothetical maximum” production of salmon smolts (ca. 18400) in River Sävarån was estimated to be higher than the previous assumed amount of ca. 4000 (Anonymous 1999). Note that I used relatively low parr densities in my calculations (compared to maximum densities of parr from other Swedish and Norwegian rivers; Johansen *et al*. 2005, Saltveit 2006, Rivinoja & Carlsson 2008), but still my estimated hypothetical maximum is greater than previously thought. Additional notes in Anonymous (1999) point out that the annual production of smolt in River Sävarån is lower than could be expected for similar sized forest rivers (i.e. comparable catchment size, reproduction area, length and flows) within this part of northern Sweden. As example, the related rivers Kågeälven and Rickleån have an estimated salmon smolt production of about 7700-11500 and 5000, respectively (Anonymous 1999). Even if the River Kågeälven has about 20% less reproduction areas than I estimated for River Sävarån, the higher juvenile densities in Kågeälven (Rivinoja & Carlsson 1998) might explain the higher smolt run estimations for this river. Conversely, River Rickleån has less than half of the parr densities found in River Sävarån and has almost 70% fewer reproduction areas (Anonymous 1999, Rivinoja & Carlsson 2008 and ICES 2008). Most likely these discrepancies are simply because previous assumptions on the smolt production for rivers in this area have been rather speculative rather than the result of an extensive quantitative study.

The average densities of salmon have increased 400-600 % over the last fifteen years in many of the rivers in this region; still trout juveniles show no clear population growth (Rivinoja & Carlsson 2008). This was true also for River Sävarån, but at the same time the increase in salmon 0+ juvenile density have been much less than in nearby forest rivers. Generally speaking, since most rivers in this region show relatively low juvenile densities in relation to internationally studied northern rivers (Johansen *et al*. 2005, Saltveit 2006) and the densities show large variation between years, this suggests that both the salmon and sea trout reproduction in this part of Sweden are unstable and most likely sensitive to disturbances.

Typically the electro-fished sites were selected to represent areas suitable for juvenile nursery. These sites also widely corresponded to habitats defined as at least “Potential” in my habitat mapping, which can be looked at in two ways. Either these areas, that were previously deemed as better than average available habitats, are able to support a majority of the returning spawners and their offspring, contributing to stable in river population requirements. At the same time, it may also cause a biased estimation of the average salmon and trout densities in the river since only feasible sites for salmon and trout parr have been electro-fished. Even so, the facts show that the sections mapped as potential juvenile habitats in general endorsed at least salmon juveniles which demonstrate that the habitat/electro-fishing method is a usable tool to estimate the salmon smolt production, also confirmed by facts that salmon generally spawn in the main stem of the rivers (Armstrong *et al.* 2003). Yet, the above discussion on the importance of tributaries for sea trout, indicates that the side branches of rivers should also be included in habitat mapping to give a more comprehensive estimation of both salmon and trout smolt production.

I suggest that my mapping survey is reliable, although the visual judgments of different river habitats suitability for various age-classes of fish are inevitably somewhat subjective. Even if the habitats were divided into classes with bottom substrate composition and water velocities corresponding to what Crisp (2000) and Armstrong *et al.* (2003) have described as appropriate for spawning and juvenile salmon and trout, the method described by Halldén *et al.* (2002) does require that similar estimation criteria are used to be able to compare rivers in various studies. Thus equivalent methods, preferably internationally standardised, should be used for mapping salmon and trout rivers to minimise any effects of personal judgment. It may also be essential to revisit some of the mapped sections during altered water levels since diverse structures may appear at different flows and also the possibility for fish to pass hindrances could change. It is worth underlining that the habitat mapping should incorporate flow conditions comparable to flows expected during the spawning period of fish and that other methods than Halldén *et al.* (2002) have been used internationally to quantify fish production. For instance the meso-habitat-method described by (Lamouroux & Capra 2002, Borsányi *et al.* 2004, Harby *et al.* 2007).

In Sweden a similar study has been performed to estimate trout smolt production (Halldén *et al.* 2005). In this study the original habitat method (Halldén *et al.* 2002) was used together with electro-fishing data. Their values on parr to smolt survival rates greatly resembled the values by Lundqvist *et al.* (2008a) that I have used even though electro-fishing data was not divided into specific year-classes for >0+ (e.g. 1+ and 2+), survival estimations when calculating the smolt production can compensate for this shortcoming. When calculating yearly smolt migration I used the same survival rates for sea trout parr as for salmon. This assumption was made because they are similar with respect to their anadromous life history traits. Still these numbers could differ, and at present relatively little is known about sea trout survival rates. Sea trout preference for spawning in tributaries may also infer higher survival for juveniles, as I interpret data on brown trout demonstrated by (Halldén *et al.* 2005).

The estimated densities of juveniles might vary between years due to electro-fishing efficiency. As mentioned by Rivinoja & Carlsson (2008), the high densities of salmon juvenile estimated in 2006 might be due to low water levels that caused fish to aggregate at fished areas and also lead to a relatively high electro-fishing efficiency. Under these circumstances the actual smolt run the following years could be overestimated. Conversely, the actual parr amount might be underestimated in years with high flows, since the electro-fishing efficiency tends to diminish at high water levels and low temperature (Murphy & Willis 1996). Furthermore, the electro-fishing accuracy depends on personal skill of the fisherman. To make the electro-fishing data more consistent, Lans (2000) recommended the following; 1) random selection of electro-fishing sites, 2) fixed start and stop points, 3) yearly sampling of areas at a restricted period, 4) catchability determined for each species year-class by three consecutive fishing at each river section, 5) registrations of environmental conditions, e.g. weather, bottom substrate, water depth and velocity. A further recommendation was that each caught individual should be measured to nearest millimetre to be able to determine the age distribution.

This survey focused on finding characteristic areas where salmon and trout can spawn and rejuvenate. The adult holding sites (Class 3) were less emphasized since fish on their spawning migration do not rely on these features in such a crucial way as resident fish. Only five of the tagged fish continued upstream after release above the fish-ladder regardless of species. All except one reached the archival unit upstream. The remaining nine fish fell back over the waterfall. These fish stayed relatively stationary for the whole tracking period at a distance of 0.3- 6 km from the fish-ladder. The finding that most of the radio-tagged adult spawners migrated downstream after being handled at the ladder was no surprise. The relatively short tagging procedure or the radio-tags themselves are not likely to induce this behaviour (Rivinoja 2005), however studies have shown that an interrupted upstream migration in the riverine migration phase can cause a delay and downstream movements (Mäkinen *et al.* 2000, Thorstad *et al.* 2007). Another reason could be that the radio-tagged adults originated from river sections downstream of the fish-ladder and homed to their natal areas (i.e. fish lacked instincts to migrate further upriver). Regardless of the reason, this could cause (and for several years also most likely have caused) an overestimation (including double counting) of fish entering areas upstream of the ladder. To minimise the fallback ratio the ladder exit could be redesigned so fish could rest and recover and/or find better upstream migration cues (Ferguson *et al.* 2002). Then again, if the fallback phenomenon is induced by evolutionary traits, e.g. site specific homing where fish were born downstream of the ladder; the spawners could still aim for downriver sections. Interestingly none of the radio-tagged fish entered the fish ladder again, and the only fish that migrated further upriver than Lake Ytterträsk/Botmarkssjön was a salmon that differed genetically from the others, certainly originating from previous stocking. Recent genetic analyses of smolts also show introgression of River Byskeälven salmon (Lundqvist *et al*. 2008b) and signifying the effects from parr stocking in River Sävarån.

During the weeks prior to spawning salmon were situated close to or in possible spawning habitat, sea trout on the other hand were found near optimal spawning habitats. Salmon did not seem as selective with spawning site selection as did sea trout; however further telemetry studies are needed to determine the generality of these observations. There was an overall change in behaviour after the spawning period when many of the radio-tagged fish migrated downstream and also left the river. This behaviour agrees with previous findings that have demonstrated that salmon and sea trout surviving the spawning do migrate seaward as kelts, either shortly after the spawning period or the following spring (Niemelä *et al.* 2000, Östergren & Rivinoja 2008). Two tag losses were registered for salmon, one that was never observed to move and thus almost certainly due to tag regurgitation (tag not retrieved), and another other tag was found on a clear cut 500m from the river.

It is not yet possible to say if the goal of 50% of the maximum natural smolt production capacity by 2010 (Anonymous 1999) in River Sävarån, has been reached or not. Even if river restorations have been carried out, more or less all northern Swedish rivers are still negatively affected by the earlier logging industry (Palm 2007). There is also a need for further studies, such as upstream migration counts and spawning site selection of both salmon and sea trout. This could aid in future efforts to restore spawning grounds in the main steam as well as in tributaries. A subsequent habitat mapping of the tributaries would also provide information on available habitats for trout production. My data do however indicate the present production level of salmon and trout in River Sävarån. Still, there are relatively large areas suitable for spawning and juvenile salmon and trout which are not utilized. At the same time the areas where the species are currently found seem to be far from fully inhabited and the number of returning spawners is low. When calculating the smolt run I have not taken into account factors such as predation, intra- or inter specific competition, density dependence, diseases (e.g. M74), all of which could have impact on natural population development (Lundqvist *et al*. 2008a).

Conclusions

As demonstrated in this work it is possible to make adequate estimates on the numbers of salmon smolt produced in rivers by combining a habitat mapping survey with electro-fishing data on juvenile densities. However, for good sea trout estimates, tributaries must also be incorporated. A previous assumption of possible reproduction areas is only half of the areal that I found as “Potential”. However most of these areas are probably not utilized by salmon and trout due to a lack of adults. Some parts of the river habitats were also overgrown by aquatic plants as well as covered by sediment and consequently efforts to restore gravel beds should take place to produce more fish. Still, these efforts would be of minor significance if there are only few returning spawners, indicating the importance of reduced sea fishing quotas.

If further studies of River Sävarån are to be conducted it could be interesting to compare the habitat mapping method that I used to other methods, e.g. the meso-habitat-methods mentioned. For further accuracy on the produced amount of smolts the number of electro-fishing sites could be increased. These sites should include randomly sampled sections to be able to compare how much juvenile densities vary depending on habitat classifications. This would result in that each habitat type presented at the river could be assigned a contribution value of juveniles to the whole smolt production. Studies in River Sävarån should also focus on upstream migration of adult salmon and trout to get an accurate figure on the total escapement.

Acknowledgements

First and foremost I want to thank my supervisor Peter Rivinoja who has been a big help with ideas, discussion and feedback on my writing, also for providing valuable information and expertise about tagging and tracking of the fish. Bo-Sören Wiklund is thanked for his technical involvement and Jan Nilsson for his help with the genetic analysis. Christer Zackrisson, Anders Kagervall, Calle Lindström, Simone Dechandt and Klaus Brackmann earn gratitude for their help and company at the tagging and tracking of fish, as well as Gunnar Andersson and Kurt Eriksson who provided us with the possibility to catch and tag fish at the ladder. Thanks also to The Swedish County Council Board of Västerbotten (Ulf Carlsson) and the National Board of Fisheries who financed the radio-tags and Andreas Broman (EcoCinclus) who came and held a course in habitat mapping methods for a small group of SLU personnel and students. The radio-tagging was carried out under licence from the Swedish Animal Welfare Agency (CFN Dnr. A5-06).

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Appendix

Table 1. Juvenile salmon caught at electro-fishing in River Sävarån. * Indicates values calculated as explained in Material and Methods (from Rivinoja & Carlsson 2008).

Year	0+ /100 m^2	>0+ /100 m^2	Total area (m^2)	Number of sites	Sites with 0+ (%)	Sites with >0+ (%)	Sum salmon	Proportion 0+ (%)
1989	0.6	0.9	2076	4	25	50	19	40
1990	1.5	3.1	3923	9	56	44	119	33
1991	0.7	4.5	3657	7	29	71	70	13
1992	0.2	3.0	3147	7	43	71	72	6
1993	1.8	1.9	2164	7	29	43	62	49
1994	1.5	2.9	3712	6	33	83	101	34
1995	0.4	1.0	4027	9	33	56	36	29
1996	10.3	2.5	3091	9	44	44	236	80
1997	0.4	3.5	3133	9	33	56	73	10
1998	2.7	2.7	2272	8	63	63	97	50
1999	0.8	5.0	3567	9	44	89	101	14
2000	12.8	7.4	1940	4	100	100	190	63
2001*	8.7	6.3	-	-	-	-	-	-
2002	4.6	5.2	3679	8	63	100	197	47
2003	2.3	4.4	4011	9	56	100	126	34
2004	2.4	6.5	1268	3	33	100	58	27
2005	3.3	3.8	3639	9	56	67	144	46
2006	12.5	16.9	2551	9	67	89	413	43

Table 2. Juvenile trout caught at electro-fishing in River Sävarån. * Indicates values calculated as explained in Material and Methods (from Rivinoja & Carlsson 2008).

Year	0+ /100 m^2	>0+ /100 m^2	Total area (m^2)	Number of sites	Sites with 0+ (%)	Sites with >0+ (%)	Sum trout	Proportion 0+ (%)
1989	0.0	0.3	2076	4	0	3	3	0
1990	3.6	1.3	3923	9	7	8	79	73
1991	1.8	1.8	3201	6	3	6	45	50
1992	0.1	6.1	3147	7	2	6	87	2
1993	2.7	2.4	2164	7	5	6	48	53
1994	0.3	1.9	3712	6	2	6	38	14
1995	0.4	0.8	4027	9	2	7	28	33
1996	3.9	1.7	3091	9	6	7	95	70
1997	0.9	2.3	3133	9	5	7	38	28
1998	0.2	1.2	2272	8	2	6	18	14
1999	1.0	0.9	3567	9	6	4	25	53
2000	0.9	0.1	1940	4	2	1	9	90
2001*	1.9	0.4	-	-	-	-	-	-
2002	2.9	0.7	3679	8	5	6	56	81
2003	2.1	2.3	4011	9	8	6	53	48
2004*	2.2	1.9	-	-	-	-	-	-
2005	2.4	1.4	3639	9	7	6	78	63
2006	2.1	2.2	2551	9	6	8	50	50

Table 3. Juvenile trout caught at electro-fishing in tributaries to River Sävarån (modified from ICES 2008).

Year	0+/100m2	>0+/100m2	Number of sites	Sites with 0+ (%)
1987	0.5	4.5	6	67
1988	29.6	8.3	3	67
1989	11.3	12.8	10	60
1990	4.4	12.0	11	55
1991	15.3	10.5	13	62
1992	15.5	13.9	13	69
1993	5.8	11.1	14	57
1994	5.9	11.8	14	50
1995	4.7	15.4	14	36
1996	2.2	4.8	10	60
1997	7.2	9.1	15	47
1998	2.0	5.1	12	42
1999	16.2	8.2	13	85
2000	5.6	8.5	13	77
2001	8.0	6.8	10	90
2002	17.9	16.6	12	92
2003	5.6	11.6	13	92
2004	6.9	9.0	14	64
2005				
2006	11.1	21.1	34	65

Table 4. Genetic probability (P) of salmon origin.

Fish ID	Length	Sex	P (Sävarån)	P (Byskeälven)
1	98	f	0.085	0.915
2	98	f	0.961	0.039
3	86	f	0.877	0.123
4	85	f	0.979	0.021
5	97	f	0.966	0.034
6	97	f	0.982	0.018
7	101	f	0.955	0.045
8	84	f	0.967	0.033
9	105	m	0.852	0.148
10	87	f	0.413	0.587
11	74	m	0.981	0.019
12	108	f	0.968	0.032