Examensarbete
i ämnet biologi

2010:1

Enumerating Atlantic salmon smolt production in River Vindelälven based on habitat availability and parr densities. - Consequences of using different density estimation methods

Stefan Ågren

Sveriges lantbruksuniversitet
Fakulteten för skogsvetenskap
Institutionen för vilt, fisk och miljö
Examensarbete i biologi, 30 hp, D-nivå, Jägmästarprogrammet

Umeå 2010

Examensarbete
i ämnet biologi

2010:1

Enumerating Atlantic salmon smolt production in River Vindelälven based on habitat availability and parr densities. - Consequences of using different density estimation methods

Smoltproduktionsuppskattning av lax i Vindelälven baserat på habitat tillgänglighet och yngeltätheter. – Konsekvenser av olika täthetsuppskattningar

Stefan Ågren

Keywords: *Salmo salar* L., Mapping, Juvenile nursery areas, Electrofishing abundance, Flow correlation, Population model

Handledare: Peter Rivinoja & Daniel Palm
Examinator: Eva Brännäs

30 hp, D-nivå
Kurskod EX0510

SLU, Sveriges lantbruksuniversitet
Fakulteten för skogsvetenskap
Institutionen för vilt, fisk och miljö

Swedish University of Agricultural Sciences
Faculty of Forestry
Dept. of Wildlife, Fish, and Environmental Studies

Umeå 2010

Abstract

Habitat mapping was conducted in the main stem of River Vindelälven in the autumn of 2009 along the salmon distribution area. The aim was to estimate the quantity of potential reproduction areas, including spawning and juvenile rearing habitats. The mapping included 61 km of various stream sections along the river length of 269 km. The total area of stream habitats was estimated to 647 ha of which 396 ha (61%) were considered as either *potential* or *optimal* juvenile nursery habitats. The area of these two habitat classes were used to estimate the smolt production in the river by using electro fishing densities of juveniles (0+ per 100 m^2). Data from the years 2001-2005 was used in four methods to estimate smolt production for the years 2005-2006. *Method 1* was based on average 0+ density multiplied with the area of juvenile habitats. *Method 2* was based on reach specific 0+ densities multiplied with reach specific juvenile areas. *Method 3* was based on reach specific 0+ densities adjusted for flow conditions multiplied with specific juvenile areas and *Method 4* was based on *Method 1* using various hypothetical juvenile densities. All methods estimated the total no of 0+ salmons on the available habitats and these were used in an age structured Leslie matrix model to estimate the smolt production. *Method 1* differed significant from both *Method 2* and *Method 3* however; there was no significant difference between *Method 2* and *Method 3.* The smolt production was estimated to c. 30 000-60 000 where *Method 1* estimated the highest smolt run. By using ArcGIS analyses of field based habitat mapping results (c. 600 ha) *Method 1* estimated c. 91 000-94 000 smolt.

Sammanfattning

En biotopkartering av Vindelälvens huvudsakliga utbredningsområde för lax utfördes under hösten 2009. Syftet var att bestämma kvalitet och arealer på uppväxtområden för juvenila lax. Resultaten visade att Vindelälven har ca 61 km varierande strömsektioner (total längd ca 269 km). Den totala arealen av strömhabitat estimerades till 647 ha av vilka 396 ha gavs antingen *goda, men inte optimala* samt *optimala* uppväxtområden för lax. Dessa två klasser användes för att kunna estimera smoltproduktionen i älven. Elfisketätheter för 0+ lax (0+ per 100 m^2) åren 2001-2005 användes i fyra olika metoder för att estimera smoltproduktionen 2005-2006. *Metod 1* baserades på älvens medeltätheter av 0+ multiplicerat med arean av uppväxtområden. *Metod 2* baserades på viktade tätheter av 0+ multiplicerat med platsspecifika arealer av uppväxtområden. *Metod 3* baserades på viktade tätheter av 0+ korrelerat mot flödesvariationer multiplicerat med platsspecifika arealer av uppväxtområden och *Metod 4* baserades på hypotetiska tätheter av 0+ med samma tillvägagångssätt som i *Metod 1.* Samtliga metoder användes för att estimera totala antalet 0+ lax på uppväxtområdena och dessa data användes i en åldersspecifik Leslie matrix modell för att skatta smoltproduktionen. *Metod 1* skiljde sig signifikant mot både *Metod 2* och *Metod 3* men det var ingen signifikant skillnad mellan *Metod 2* och *Metod 3.* Smoltproduktionen estimerades till ca 30.000-60.000 där *Metod 1* skattade flest smolt. Vid skattningar med ArcGIS med grund från fältkarteringen (ca 600 ha) i kombination med *Metod 1* estimerades smoltproduktionen till ca 91 000-94 000 smolt.

Introduction

Generally there is a lack of knowledge about the present and potential production of Atlantic salmon (*Salmo salar* L.) and seatrout (S*almo trutta* L.) in northern European rivers (ICES 2008). Previous assumptions have been based on limited information on the amount of potential production areas at specific rivers causing irregularities and uncertainness between the different methods applied (Molin 2008), which has lead to a considerable variation of the estimated smolt production (ICES 2008). This includes tentative estimations of reproduction areas (including spawning sites and juvenile nursery areas) which together with indecisive density enumeration of juveniles might have caused inaccurate predictions of the smolt production (Molin 2008). At the same time the recent restrictions in offshore fishing has not been incorporated in the smolt production modelling. Nevertheless, if the amount of returning spawners will increase together with habitat availability after river restorations the future populations of anadromous salmonids may possibly be favoured (Lundqvist *et al.* 2008). However, the production is limited by several factors like: size, quality and accessibility of spawning habitats together with water chemistry, flow amount and diseases incidents etc. (e.g. Armstrong *et al.* 2003; ICES 2007; Molin 2008).

In 1997 the International Baltic Sea Fisheries Commission established a management plan for the Baltic salmon populations; the natural producing salmon rivers should produce ≥50% of their potential smolt production by year 2010 (ICES 2007). However, the potential smolt production in Baltic salmon rivers is difficult to estimate due to limitations in the amount of vital information in most of the rivers (ICES 2008). The smolt production also varies among years with varying environmental factors (water flow, temperature, feeding possibilities, etc.) (Heggenes *et al.* 1996; Armstrong *et al.* 2003; ICES 2008; Rivinoja & Carlsson 2008). Nevertheless, assuming that quality and accessibility of spawning grounds are not limiting the production, knowledge about wetted useable area (available production habitats) needs to be studied. The information is gained through various methods of habitat mapping (Bovee *et al.* 1998; Borsányi *el al* 2004; Molin 2008), which in combination with juvenile densities estimations may provide smolt run estimations (Molin. 2008).

In Sweden the recruitment of salmon parr is generally annually monitored with electric fishing by County administrations. In River Vindelälven, c. 19 fixed sites are normally monitored annually. These have been sampled since year 1984 by using the Swedish standard electric fishing methods (Degerman & Sers 2001). The calculated juvenile densities at these sites are generally considered to represent comparable stream sections within the river. However, since juvenile salmon tend to utilize various habitats in the main steam (i.e. micro habitats at stream margins) and tributaries (Armstrong *et al.* 2003; Blank *et al.* 2007), all year classes are not fully represented in the samples (Carlstein *et al.* 2005). In contrast to a small stream where the whole width can be sampled, a large river like River Vindelälven is limited to be fished at the shallow areas close to shoreline. This may cause an underrepresentation of older year classes (≥1+). Nevertheless, 0+ juveniles tend to use the stream margins (Armstrong *et al.* 2003; Blank *et al.* 2007) and are assumed to be fully represented in the electro fishing estimates as long as the efficiency is comparable. Due to the factors mentioned all estimates in this report are estimated from 0+ densities.

To estimate the smolt production within a river there are several methods to use (e.g. Borsányi *et al.* 2004; ICES 2007; Molin 2008; Cowx *et al.* 2009). The most widely smolt production estimate is based on electric fishing densities in addition to available juvenile areas. Molin (2008) demonstrated a method where the amount of suitable habitats was multiplied with juvenile densities to estimate smolt production, assuming that the average parr density represent all potential juvenile areas. However, juvenile density can vary within river sections (e.g. Armstrong *et al.* 2003; Mäki-Petäys 2004; Carlstein *et al.* 2005; Blank *et al.* 2007; Rivinoja & Carlsson 2008). Consequently a more fine scaled method, based on reach specific densities, would almost certainly give higher accuracy in production potential estimates. In accordance to this, since flow conditions may affect the electro fishing efficiency, density estimations may be imprecise (ICES 2007; Rivinoja & Carlsson 2008). Thus, knowledge of flow conditions during the electro fishing period needs to be carefully considered in smolt estimations in order to not over- or underestimate the juvenile densities. To evaluate the reliability of smolt production estimates based on electro fishing data and to develop consistent methods for the future, scientific comparisons between different methods needs to be accomplished, and if possible be validated with collected field data. This study used a habitat mapping of the total available amount of juvenile habitats, electro fishing densities of 0+ salmon parr (average, reach specific, reach specific adjusted for flow and hypothetical densities) together with an age structured Leslie Matrix model to estimate the smolt production in River Vindelälven. The estimated densities year 2001-2006 was used to predict smolt run for the years 2005 and 2006 when all year classes of juveniles contribute to the smolt production.

The aim with this study was to estimate the production of salmon smolt in River Vindelälven. First, a habitat mapping was conducted to estimate the total available area of potential and optimal juvenile habitats. Secondly, these areas were used in four methods predicting the smolt production based on:
1) whole river 0+ density average
2) reach specific 0+ density
3) reach specific 0+ density adjusted for flow conditions
4) based on hypothetical densities using *Method 1.*
Thirdly, ArcGIS analyses of field based habitat mapping results from Leonardsson (2010 *pers. comm.*) of the potential juvenile nursery areas were applied to *Method 1* and *Method 4* to estimate the smolt production.

Material and Methods

Study area

The River Vindelälven originates in the Scandinavian mountains and flows in a south-easterly direction for about 400 km where it joins the river Umeälven approximately 42 km upstream from the outlet in the Bothnian Bay at 63°50´N, 20°05´E (Fig. 1). The river follows a snow-dominated flow regime with a typical maximum flow of 1000 m^3s^{-1} during snowmelt in June. Average annual discharge is 180 m^3s^{-1} with a minimum winter discharge of 40 m^3s^{-1}. Generally the river is covered by ice from November to April. The fish fauna is predominated by Atlantic salmon, brown trout *Salmo trutta* L., northern pike *Esox lucius* L., Eurasian minnow *Phoxinus phoxinus* L., burbot *Lota lota* L., Eurasian perch *Perca fluviatilis* L. and European grayling *Thymallus thymallus* L. Salmon reproduction take place in late October along the lower 250 km of the river (Swedish Electro fishing Register, SERS). The riparian surroundings consist of managed boreal coniferous forest predominated by Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* L.).

River Vindelälven is annually electro fished by the County board of Västerbotten with normally 19 fixed electro fishing sites. The sampling (one removal) is normally conducted in autumn (late August/September) prior to the salmon spawning period and when the water discharge is stable (Rivinoja & Carlsson 2006).

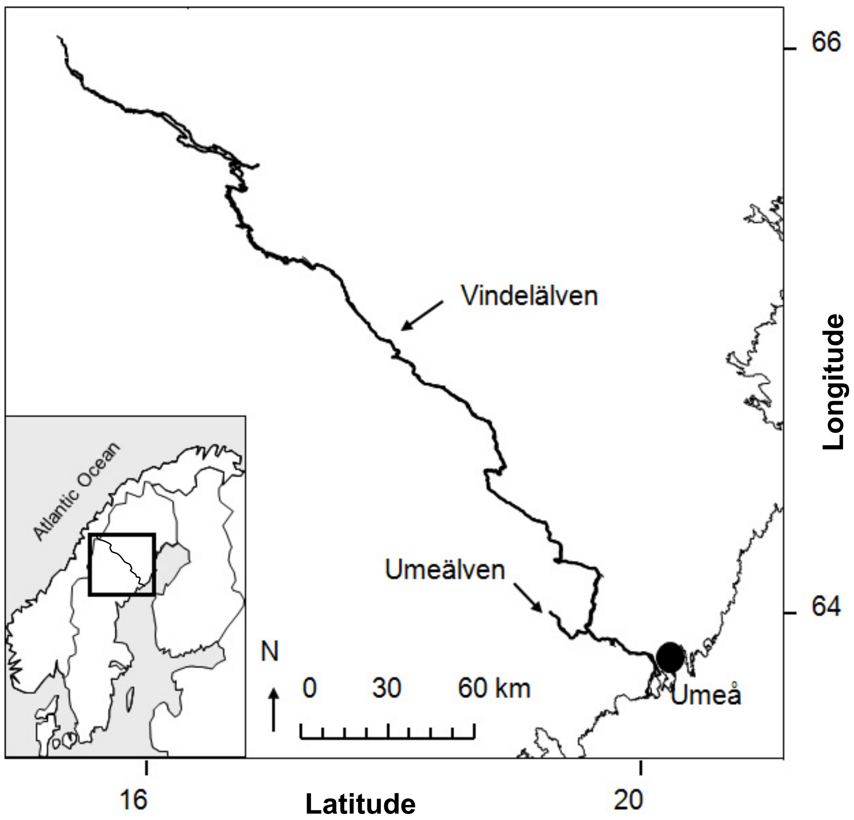

Figure 1. *Map showing geographical position of River Vindelälven.*

Area of juvenile habitat

To estimate the potential and optimal availability of juvenile areas, a habitat mapping was conducted in the main distribution area where salmon are known to reproduce (Östergren 2005). This includes, 269 km of river between rapid Vännforsen (c. 51 km from sea) and rapid Stensundsforsen (c. 320 km from sea), with tributaries excluded. The habitat mapping generally followed the Swedish standard method (Swedish Environmental Protection Agency, Naturvårdsverket 2003) in combination with the Norwegian meso-habitat mapping method (Borsáni *et al.* 2004, details in Wikman-Myrestam 2010 in press). The parameters measured were: 1) Habitat quality for juvenile salmon (0-3) according to Table 1. 2), Stream velocities (Slow flowing (<0.2 m s^{-1}, 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^{-1}, highly turbulent water)), 3) Bottom substrates (Fine detritus, rough detritus, clay (<0.02 mm), sand (0.02-2 mm), gravel (2-20 mm), stone (20-200 mm), boulder (>200 mm) and rocks (>4000 mm)) and 4) Width (m) (≥2). All parameters except *habitat quality* and *width* were given in percent (%) of total area since several bottom substrates compositions were visually estimated at the mapping. All mapped sections were given specific lengths using software ArcGis (9.2) respectively. The area could thus be calculated correspondingly for each section using *average width * length*. All sections which was given either potential (2) or optimal (3) as juvenile habitat was grouped to be able to estimate juvenile salmon densities (assuming a section given suitable can hold as many juveniles as an optimal area), following the method by Molin (2008). See Wikman-Myrestam (2010 in press) for a more detailed description of the habitat mapping method.

Table 1. *Classification of habitat suitability for juvenile nursing areas (modified from Molin 2008).*

Habitat type	Class 0	Class 1	Class 2	Class 3
Quality of nursery habitat	Not suitable	Possible, not satisfactory	Reasonably good, not optimal	Suitable with optimal nursery conditions

Methods to estimate juvenile density and smolt production

Smolt production was estimated by using four different methods to calculate 0+ density: *Method 1*) based on whole river 0+ density average, 2) reach specific 0+ density, 3) reach specific 0+ density adjusted for flows, and finally 4) hypothetical maximum 0+ densities. The estimated smolt production using *Method 1* requires data on *area of juvenile habitat* and *average 0+ juvenile density*. For estimates by *Method 2* data is also needed on *reach specific 0+ juvenile density*. Smolt production estimations by *Method 3* requires additional data on *electro fishing efficiency in relation to flow conditions*. Finally *Method 4* uses *hypothetical 0+ densities* and area of juvenile habitat. Parameters in italics are further described below. These four methods were used to estimate smolt production based on areal mapping in the field. In addition, *Method 1* and *Method 4* was applied to an estimated area of c. 600 ha potential juvenile areas, using ArcGIS analyses data (Leonardsson 2010 *pers. comm.*) combined with the field based habitat mapping data.

Method 1: Average juvenile density

Average densities of 0+ juveniles were calculated from available electro fishing data, gained from the County administration of Västerbotten. At each sample site the density of 0+ per 100 m^2 was estimated (assuming a catchability of 0.45 in accordance to Degerman & Sers (2001). Thereafter an overall average density was calculated for all the sampled sections together for the years 2001-2006. Finally the average density was multiplied with the total amount of potential and optimal juvenile nursery areas (representing class 2 and 3 in Table 1) in order to calculate the total number of 0+ juveniles at the specific areas.

Method 2: Reach specific density

Due to unknown densities at potential and optimal river sections (areas not entirely sampled by the electro fishing) a fine scaled method was used to predict the 0+ density. For these reaches a weighted densities was estimated respectively for each section (Equation 1 and Figure 2), assuming that nearby localities show similar densities as the sampled sites, diverging with distance. These values where then multiplied with site specific areas to estimate the total number of 0+ for the years 2001-2006.

(1) $$\overline{N} = \sum_{i=1}^{n}((N_{ui} / d_{ui}) + (N_{ni} / d_{ni})) / \sum_{i=1}^{n}(1/(d_{ni} + d_{ui}))$$

Formula 1. Used to estimate densities at unknown sections based on electro fishing densities where:

N_u = Density of 0+ in electrofishing site upstream unknown section.
N_n = Density of 0+ in electrofishing site downstream unknown section.
d_u = Distance from unknown site to electrofishing site upstream.
d_n = Distance from unknown site to electrofishing site downstream.

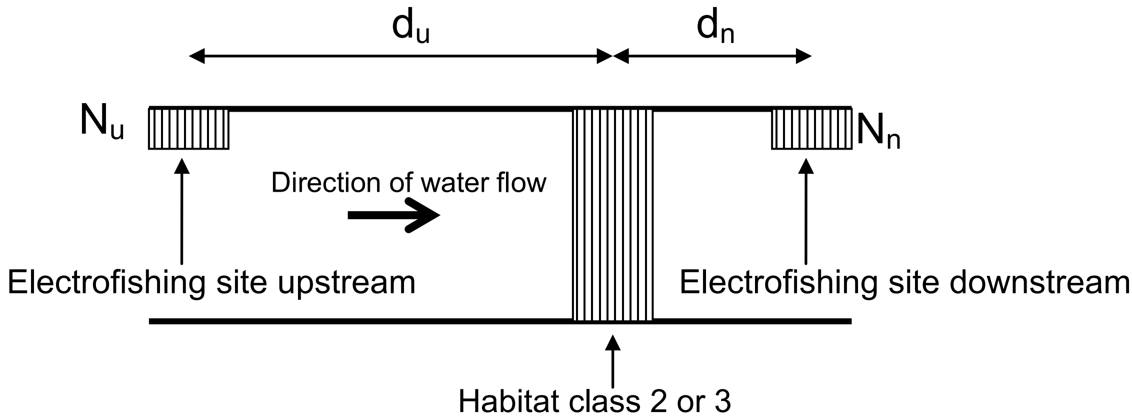

Figure 2. *Description of how the reach specific densities are calculated with descriptions for each parameter in the formula (formula 1).*

Method 3: Electrofishing data and flow conditions

To test if river discharge can affect the electrofishing efficiency, and thus the estimated densities, flow data (obtained from the Swedish Metrological and Hydrological Institute, SMHI) was analysed for the electrofishing periods in 1984-2008 (Table 2). Firstly, the average flow for these years was divided by the actual flow at each sampling occasion, generating a *Flow factor*. Secondly, the reach specific density was multiplied with the flow factor (*Reach specific density * Flow factor*). The flow adjusted densities (average 0+ per 100 m^2) were then correlated to the mass of spawning females the previous year. This data was then contrasted to juvenile densities not adjusted for flow (data from Rivinoja & Carlsson 2008). Thus it was possible to test if flow amount affected the electrofishing outcome. Finally, the years 2001-2006 was used in the smolt production estimate.

Table 2. *Flow at electrofishing period, the density of 0+ salmon and the mass of female salmon the years 1986-2008.*

Year	Flow (m3/s)	0+ density	Kg females
1986	88,7	1,13	473
1987	-	-	359
1988	-	-	1359
1989	175,2	1,57	625
1990	195,4	0,57	2476
1991	158,9	2,28	1128
1992	-	-	1754
1993	258,6	0,29	2663
1994	75,7	0,51	4085
1995	113,3	0,39	1033
1996	128,3	0,30	7131
1997	126,8	17,23	7170
1998	201,2	21,59	1617
1999	89,7	3,29	4655
2000	183,8	4,53	2978
2001	305,5	3,54	6037
2002	87,5	24,02	11998
2003	124,0	23,69	6519
2004	159,0	17,69	3995
2005	249,6	3,69	9200
2006	112,3	14,21	7074
2007	166,5	14,84	8630
2008	177,3	7,26	13947

Method 4:

Using *Method 1* and 0+ average hypothetical densities of 40, 60, 80 and 100 per 100 m^2, typically observed in Scandinavian rivers the smolt production was estimated. These values were based on data from other Atlantic salmon rivers e.g. Mörrumsån (Southern Sweden; c. 60-120 0+ per 100 m^2) (ICES 2007), Altaälven (Northern Norwegian river, 50-80 0+ per 100 m^2) and Varzuga (Kola peninsula Russia, c. 80-130 0+ per 100 m^2) (Andersson 1998), predicting possible future smolt run in River Vindelälven at a population increase.

Smolt production

To estimate the total smolt production in river Vindelälven an age structured, Leslie matrix model was used. Probability of various survival parameters (Table 2) was used following Ferguson *et al.* (2008) and Lundqvist *et al.* (2008). Firstly, the estimated number of 0+ (Js) from the four methods was used. Secondly, the numbers of 0+ was multiplied with river survivals for each age class respectively. Third, the propensity of smoltification at specific ages was multiplied to estimate the smolt production. The four estimated densities the years 2001-2006 were used to estimate the smolt production the years 2005 and 2006 (Table 3).

The three methods to estimate smolt production from the field mapping: 1) whole river 0+ density average 2) reach specific 0+ density 3) reach specific 0+ density adjusted for flow conditions was compared using General Linear Modelling combined with Tukey's post hoc test. The test was conducted on the period 2003-2010. All statistical calculations were conducted using Minitab 15, Minitab Inc. State College, Pennsylvania, U.S.A. Finally, ArcGIS data from data Leonardsson (2010 *pers. comm.* 2010) was used to estimate the smolt production using *Method 1* and *Method 4*.

Table 3. *Life cycle matrix model input parameters from Lundqvist et al. (2008).*

Description	Parameter	Probability of survival
Number of 0+ salmon parr	*Js*	
River survival (0-1 year)	S1	0,4
River survival (1-2 years)	S2	0,4
Propensity to smolt at age 2	Sm2	0,286
River survival (2-3 years)	S3	0,6
Propensity to smolt at age 3	Sm3	0,6
River survival (3-4 years)	S4	0,6
Propensity to smolt at age 4	Sm4	1

Results

Area of juvenile habitat

The mapped stretch in River Vindelälven had a total length of c. 269 km where c. 61 km consisted of rapids, runs and glides and was considered to hold juvenile salmon habitat. The other parts of the river, e.g. slow flowing sections and lakes, were considered as non suitable juvenile habitats based on general salmon preferences (e.g. Mäki-Petäys *et al.* 2004) which were assumed not to contribute to smolt production in the main steam of the river. The habitat mapping resulted in 163 unique stream sections of various area and suitability. The total area of stream habitats was estimated to c. 647 ha of which c. 396 ha was classified as potential (2) or optimal (3) for juvenile rearing. During the whole sampling period River Vindelälven had low and stable discharge (SMHI 2008) which thus contributed to a consequent mapping of the parameters which otherwise could have biased the results.

Method 1. Average juvenile density

The whole river 0+ density average varied considerably. Between year 1986 and 2008 the densities varied between c. 3-24 of age 0+ per 100 m^2 (Table 2). However, the years 2001-2006 was used in the estimates and the total number of 0+ on the suitable and optimal habitats from field mapping varied between c. 140 000-950 000 individuals (Table 4). This resulted in an estimated smolt production of c. 60 000-62 000 individuals (Figure 5) the years 2005 and 2006. Using ArcGIS data of potential and optimal nursery areas the smolt production varied from 91 000-94 000 individuals year 2005 and 2006.

Method 2. Reach specific density

The estimated total numbers of 0+ on the suitable and optimal habitats based on reach specific densities were estimated to c. 120 000 – 725 000 individuals for the years 2001-2006 (Table 4). This resulted in a total smolt production of c. 44 000-46 000 individuals (Figure 5) the years 2005 and 2006

Method 3. Reach specific densities adjusted for flow conditions

The estimated total numbers of 0+ on the suitable habitats based on reach specific densities adjusted for flow conditions were estimated to c. 212 000-608 000 individuals for the years 2001-2006 (Table 4). This resulted in a total smolt production of c. 33 000-41 000 individuals (Figure 5) the years 2005 and 2006.

A large flow variation was noted between years at the electrofishing occasions (typically during August). The average flow was estimated to c. 160 m^3s^{-1} with a variation from c. 75 m^3s^{-1} (year 1994) to c. 300 m^3s^{-1} (year 2001) (Figure 3). Adjusting electrofishing data with respect to flow conditions had a substantial influence on estimated total number of 0+ salmon (Figure 4). Consequently the relationship between 0+ density and mass of healthy females improved from R^2=0.56 to R^2=0.68 (Figure 4) when adjusting for flows. Indicating that the calculated juvenile densities were lower at high flows.

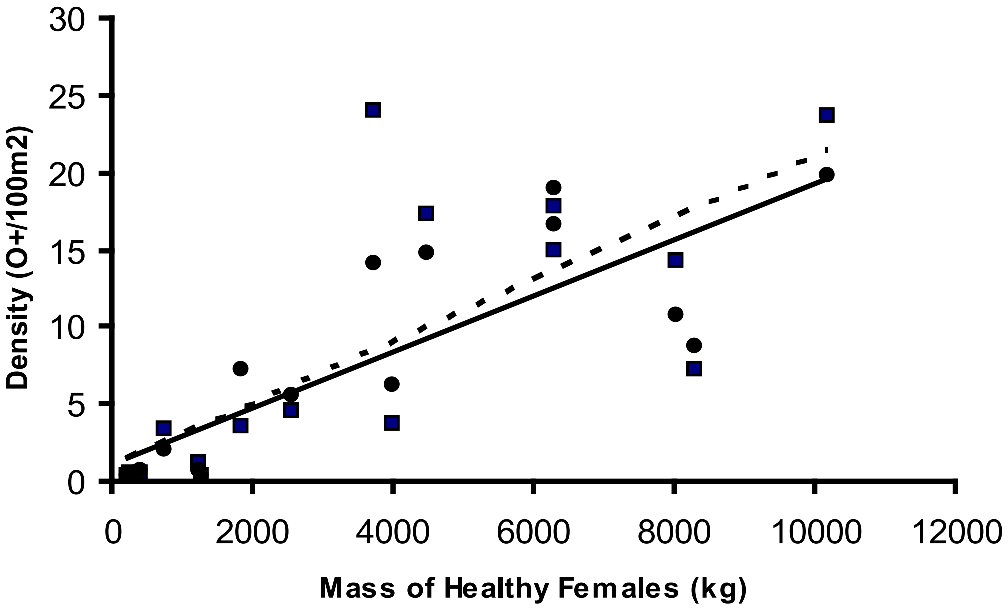

Figure 4. *Density of 0+ salmon the years 1986-2008 in relation to mass of healthy females (M74 is subtracted) the prior year. The squares represent the density observed from electrofishing (Dotted line; R^2=0.56) (Rivinoja & Carlsson 2008) and the circles represent the density adjusted for flow conditions (Solid line; R^2=0.68).*

Method 4. Hypothetical densities

The estimated smolt production using an average of 40 0+ per 100 m^2 estimated c. 117.000 smolt. Average of 60 0+ per 100 m^2 estimated c. 175.000 smolt. Average of 80 0+ per 100 m^2 estimated c. 234.000 smolt and average of 100 0+ per 100 m^2 estimated c. 292.000 smolt. All estimates were based on *Method 1* (average density * area of suitable habitats mapped in field). Based on ArcGIS data of potential and optimal nursery areas the smolt production varied from c. 177 000, 265 000, 443 000 and 446 000 individuals, respectively.

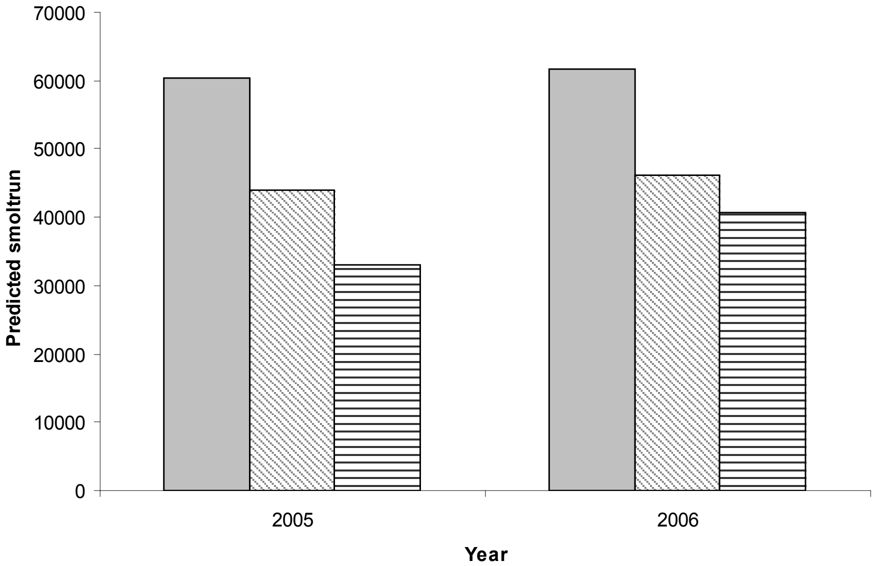

Figure 5. *Estimated total salmon smolt production. 1) Estimates based on whole river 0+ density average (filled bar), 2) Estimates based on reach specific 0+ density (downward diagonal filled bar), 3) Estimates based on reach specific 0+ density adjusted for flow conditions (vertical filled bar).*

Differences between methods

General Linear Model revealed significant (F=8.75, DF=2, P=0.003) difference between estimated smolt run for the various methods. *Method 1* estimated higher smolt production than both *Method 2* (P=0.021) and *Method 3* (P=0.004) (Tukey's post hoc test). The predicted smolt production by *Method 3* was on average about 79% of the one derived by *Method 1*. The above differences resulted from variations in both juvenile densities and area estimations for the three methods. Systematically *Method 1* estimated higher juvenile amount than *Method 2*, ranging from c. 15-40% higher amounts between the years (Table 4). Comparing *Method 1* to *Method 3*, indicated values ranging from c. 60-220% for the years, consequently *Method 1* predicted both lower and higher juvenile amounts than *Method 3*. No significant differences between *Method 2* and *Method 3* was found (P=0.633) in smolt production.

Table 4. *Total estimated numbers of 0+ salmon parr in River Vindelälven the years 2001-2006. Estimations based on electrofishing densities and the total area of suitable habitats.*

Year	*Method 1*	*Method 2*	*Method 3*
2001	140084	119684	245441
2002	950516	724547	425818
2003	937458	647381	538935
2004	700026	569560	608086
2005	146027	126262	211518
2006	562167	399388	300977

Discussion

Smolt production

All the smolt production estimates in this report are comparable to previously reported (e.g. Rappe *et al.* 1999). ICES (2007) estimated the smolt production year 2005 to c. 35 000 (11 000-354 000) and year 2006 to c. 45 000 (14 000-426 000). However, previous assumptions about the amount of potential nursery habitats have been rather rough, i.e. based on expert knowledge by ICES (2007). A similar field mapping in addition to a rough map analysis by Perä (2006) resulted in an area of c. 1093 ha. However previous methods did not use detailed field based mapping as in this report. Consequently the previous methods may have overestimated the smolt production in the river by using an overestimated amount of potential nursery habitats. The amount of potential and optimal nursery areas in this report was c. 68% smaller than demonstrated by ICES (2007), 396 ha versus 1246 ha. Nevertheless, adding up the total available stream habitats (c. 647 ha) the area was still c. 48% smaller than ICES (2007). However, both Perä (2006) and ICES (2007) included the big tributary Laisälven in their estimates and may thus be the main reason for the area differences. A recent ArcGIS analysis by Leonardsson (2010 pers. comm.) indicates similar area estimations as Perä (2006) and ICES (2007) at the same river stretch when using the mapping data from this report. Yet, if tributary Laisälven was excluded from the analysis the total area was on average c. 35% larger than indicated in this report, which concludes that the total wetted area is overestimated when performing map analyses in e.g. software ArcGIS (Leonardsson 2010 *pers. comm.*). Nevertheless, using ArcGIS data on the potential juvenile nursery areas the smolt production was estimated to c. 91 000-94 000 individuals which still harmonizes relatively well to previous reported by e.g. Rappe *et al.* (1999) and ICES (2007) however, probably an overestimation compared to this report as previously discussed. As flow affects the habitat availability for fish, the relatively low flow during the period of mapping in this study may have affected the estimated suitable areas to become low. Flow amount is generally limiting available habitats in many rivers (Harby *et al.* 2007). The production area in River Vindelälven may be even smaller during years of low precipitation (min flow estimated to c. 40 m^3s^{-1})

Studies and electrofishing surveys have shown relatively high densities in several tributaries to the river (Andreasson *et al.* 2005). This indicates that tributaries should be taken into account when estimating the total smolt production within a river catchment. At present there is no indication of salmon spawning in the smaller tributaries, however juveniles may use these sites as nursery areas. This does not only mean that the potential nursery areas increases but may also cause lower densities in the main steam if juveniles migrate into tributaries.

The production estimate in this report of c. 75-150 smolt/ha (*Method 1-3*) are similar to the estimates from River Sävarån of c. 75 smolt per ha (Molin 2008). Previous estimates by ICES (Karlsson & Karlström 1999) indicates a production in River Vindelälven of c. 200 smolt per ha. Consequently the estimated smolt production per ha harmonizes relatively well with these formerly reported numbers.

As indicated in the results the estimated production of salmon smolt ranges from c. 30 000 – 60 000 yearly based on the observed electrofishing densities (years 2001-2005) depending on which method used. These estimations may be lower than the actual production, caused by underestimation of the juvenile densities gained from the electrofishing and because that there may be more suitable stream habitats (nursery areas) than found at the mapping of the river. As example Degraaf & Bain (1986) found that slow flowing areas and riffles had comparable densities of salmon juveniles, indicating that several factors may affect fish preferences. This concludes that other sections than the mapped ones may be inhabited by juveniles, which indicates that River Vindelälven may have even larger areas of suitable quality for juveniles. Thus the juvenile monitoring should be expanded from present riffle areas to gain better information of habitat preferences in various river sections.

Even if the shoreline electrofishing is inevitably limited it gives an indication of the general trend in salmon population development since it takes place annually and provides long term data series. The density estimates showed an increasing trend in juvenile density from year 1986 to 2008. This is clearly correlated to the increasing amount of female spawners as demonstrated in Table 2 (also indicated by Rivinoja & Carlsson 2008). The smolt production estimated for the years 2005-2006, demonstrated significant differences dependent on the methods used to calculate juvenile abundances. All three methods use fixed survival rates in the Leslie matrix model which however may vary within the river by years due to biotic- and abiotic factors. Similarly, the smolt production estimations make assumptions that can cause irregularities in the predictions. This is due to that only 0+ densities were regarded in the smolt estimations and that smoltification can happen at various ages dependent on inter-annual variation and environmental conditions at various river sections. Likewise there might be a variation in juvenile survival between years, which could not be regarded since this type of data is lacking for most northern rivers. In future the smolt run estimations will be more accurate and the modelling can be tested to data collected from a smolt trap recently installed at the river.

The hypothetical densities used indicated a larger smolt run than other estimations tested due to the higher amount of 0+ juveniles. The hypothetical densities used in this report were based on other Atlantic salmon rivers in northern European rivers. Since these rivers shows higher densities of juvenile salmons than the River Vindelälven the river population could almost certainly increase if the number of spawners were higher (combining findings by Andersson 1998, Lundqvist *et al.* 2008).

At rare occasions some electrofishing sites in River Vindelälven have shown densities of more than 100 of age 0+ per 100 m^2, indicating that neither the river characteristics nor the amount of suitable juvenile habitats are limiting a future population increase. An increase from present density of about 20 of age 0+ per 100 m^2 to 40 per m^2 would double the smolt production according to the model predictions in this report.

Aspects of the various calculation methods

The contrasted three methods used in this study require analogous baseline data on the amount of suitable juvenile habitats together with juvenile density quantifications. *Method 2* however, requires additional calculations while *Method 3* requires flow data. Nevertheless, if flow data is available I recommend the use of *Method 3* in smolt production estimates. *Method 1* is least time consuming, but *Method 3* is likely to give the most accurate estimations.

As stated, *Method 1* is the simplest way to predict smolt production. However, in larger rivers this may give uncertain estimations if data is pooled for several sites due to variation in habitat suitability and juvenile densities. This may cause both an under- and overestimation of the densities, thus the juvenile sampling should include a wide range of habitat types. In addition, if the amounts of spawners and/or spawning areas are limited, juveniles may be lacking at sites mapped as suitable or optimal nursery areas. Some electrofishing sites shows high densities (>100 of 0+ per 100 m^2) whereas other sites may lack juveniles some years. To avoid possible interactions of the factors above a new approach by *Method 2* was tested here to get a higher resolution of the density variation in the river.

By *Method 2* a more detailed analysis of both the site specific juvenile densities and habitats were executed, likely to produce a more correct estimation of the smolt production than *Method 1*. The various sampling sites showed rather large difference, with relative low juvenile densities observed in some sections of the river. The juvenile densities estimated here are apparently related to spawning site selection of females as reported by Östergren (2006). The model estimates highest densities in the upper part of the river where the main spawning areas are located, in the middle part juveniles are found less frequent (no spawning areas or not used spawning areas) however, increasing again at the lower parts where the second main spawning areas are found (Östergren 2006).

The density adjusted for flows conditions (*Method 3*) have not, to my knowledge, previously been tested. Clearly, when correlated to flows, there was an improvement in the relationship between the potential spawning mass of females and the estimated juvenile density the following year. However, the estimated juvenile densities may vary due to several reasons. For instance the electrofishing efficiency is flow dependent (Murphy & Willis 1996), which is also indicated in this report. Another explanation might be that the electrofishing is normally carried out at limited areas (the wadeable zone) close to shoreline, consequently leading to an underestimation of larger fish that may dwell at deeper waters (e.g. Crisp 2000). The fact that older juveniles may prefer wider river sections than 0+ has been demonstrated in several studies (Mäki-Petäys *et al.* 2004; Breau *et al.* 2006). As noted by boat electrofishing in River Vindelälven, habitats that were previously assumed as less suitable for juveniles were inhabited by several year classes of juveniles (Carlstein *et al*. 2005). As a result of this the density estimations from the traditional shoreline electrofishing may be underestimated by 20-40% (Carlstein *et al*. 2005). A further reason that may affect the sampling outcome is the location of sampling sites that are dependent on water levels. Consequently sites that are fished at low flows cannot be sampled at high flow events. In addition to this, various flow regimes change the physical character of the river due to various stream velocities, which may cause habitat shifts among fish (Bunt *et al.* 1999). Because of the varying flow amounts between electrofishing samplings there may be irregularities in the data set. For instance Rivinoja & Carlsson (2008), that analyzed 15 year of data, found only weak correlations in the estimated densities of 0+ in relation to ≥1+ densities the following year. Even if *Method 3* included the flow adjustments there is still 32% (R^2=0.68) of variation that is not fully explained, which may be due to various spawning success of the females in River Vindelälven which was also indicated by Barant *et al*. (2003). Nevertheless, to reduce inconsistency in the sampling method, flows should be regarded while estimating juvenile density from electrofishing data.

Conclusions

This report has contributed with some interesting results. The habitat mapping of the river gave new knowledge about the total amount of available juvenile nursery habitat during low flow discharge and was lower than previous estimates made by e.g. Perä (2006) and ICES (2007).

The smolt production estimates harmonizes relatively well with previous reported however indicates a lack of knowledge of the actual production. This is due to irregularities in the density estimation methods, area estimation methods and modelling of the river survivals. However, if future smolt production estimates are to be carried out the reach specific method (*Method 2*) should be used since it gives a more detailed and site specific density estimate. Nevertheless, since the statistical analysis did not show any significant difference between *Method 2* and *Method 3* on the smolt production estimate, the discharge may be of less importance however should be seriously considered while performing electrofishing surveys.

To be able to estimate the production in the future there is a need of making additional research on juvenile survival in the river to be able to make more valid smolt estimate models. Also, standardize a method to estimate the amount of nursery areas in rivers to reduce inconsistency between scientists. Finally, the monitoring of juvenile salmon should be expanded into a larger variety of habitats to gain better knowledge of the habitat preferences to be able to make more accurate density estimations.

Acknowledgements

Without Putte, the field work had been undoable. I want to thank my supervisors Peter Rivinoja and Daniel Palm for all the work and time they have put in to this report and for being excellent educators and persons. Vindelälvens Fiskeråd - Daniel Holmqvist and Stig Westberg for the financial support and the expert knowledge. Daniel Jonsson for expert knowledge and guidning in the river. Bo-Sören Wiklund for help with his fantastic technical skills. Kjell Leonardsson for his mathematical skills. Ulf Carlsson for all data from the electrofishing surveys and interesting discussions. Gustav Hellström for the statistical analyses. Eva Brännäs my examinator. Professor Hans Lundqvist. The staff at Norrfors hatchery for their co operation and data. All my family and friends and all the people who helped us during the mapping period at the river.

References

Andreasson A, Katsogiannos T, & Olesen M. 2005. Vad betyder små biflöden för laxproduktion i stora älvar? *Projektarbete i Fiskevård (5 p) Sportfiskeakademin KY Forshaga HT 2005.* (In Swedish).

Armstrong JD, Kemp PS, Kennedy GJA, Ladle M, Milner NJ. 2003. Habitat requirements of Atlantic salmon and brown trout in rivers and streams. *Fisheries Research* **62**: 143-170.

Birzaks J. 2005. The River Salaca salmon habitat mapping. *GEF Baltic Sea Regional Project. Phase 1: 2003-2005.*

Blank A, Tedesco P-A† & Lamouroux N. 2007. Relationships between life-history strategies of European freshwater fish species and their habitat preferences. *Freshwater Biology* **52**: 843–859.
Bohlin, T. 1984. Kvantitativt elfiske efter lax och öring – synpunkter och rekommendationer. *Information från Sötvattenslaboratoriet, Drottningholm* **4:1984**, 33 sidor. (In Swedish).
Borsányi P, Alfredsen K, Harby A, Ugedal O, Kraxner C. 2004. A meso-scale habitat classification method for production modelling of Atlantic salmon in Norway. *Hydroécologie Appliquée,* Tome **14(1)**: 119–138.
Bunt, C.M., Cooke, S.J., Katopodis, C. & Mckinley, R.S. 1999. Movement and summer habitat of brown trout (*Salmo trutta*) below a pulsed discharge hydroelectric generating station. Regulated Rivers: Research & Management **15(5)**: 395-403.
Carlstein M., Bruks A. & Boberg J. 2005. Beståndsuppskattning och inventering av laxungar i Vindelälven 2005. *Rapport. Fiskeresursgruppen, Älvdalens utbildningscentrum. 13 sidor.* (In Swedish).
Crisp DT. 2000. Trout and Salmon Ecology, Conservation and Rehabilitation. *Oxford: Fishing News Books.* ISBN 0-85238-256-1.
Cunjak RA & Therrien J. 1998. Inter-stage survival of wild juvenile Atlantic salmon, Salmo salar L. *Fisheries management and Ecology* **5**: 209-223. *Reviews in Fish Biology and Fisheries* **3**: 39-73 (1993)
Degerman E, Sers B. 2001. Elfiske. Standardiserat elfiske och praktiska tips med betoning på säkerhet såväl för fisk som fiskare. *Fiskeriverket information* 1999:3 Fiskeriverket, Sötvattenslaboratoriet, 702 15 Örebro: 3-69. (In Swedish).
Degraaf DA. & Bain LH. 1986. Habitat use and Preferences of juvenile atlantic salmon in two Newfoundland rivers. *Transactions of the American Fisheries Society* 1986; 115: 671-681.
Finstad A.G., Økland F., Thorstad E.B. & Heggberget T.G. 2005. Comparing upriver spawning migration of Atlantic salmon Salmo salar and sea trout Salmo trutta. *Journal of Fish Biology* **67**: 919–930.
Garant D., Dodson J.J. & Bernatchez L. 2003. Differential reproductive success and heritability of alternative reproductive tactics in wild Atlantic salmon (Salmo salar L.). *Evolution* **57(5)**: 1133–1141.
Gibson R.J. 1993. The Atlantic salmon in fresh water: spawning, rearing and production. *Reviews in Fish Biology and Fisheries* **3**: 39-73.
Halldén A, Liliegren Y, Lagerkvist G. 2002. Biotopkartering- Vattendrag. Metodik för kartering av biotoper i och i anslutning till vattendrag. ISSN: 1101-9425. *Meddelande nr 2002:55*. Länsstyrelsen i Jönköpings län. (In Swedish).
Halleraker JH, Sundt H, Alfredsen KT & Dangelmaier G. 2007. Application if multiscale environmental flow methodologies as tools for optimized management of a Norwegian regulated salmon watercourse. *River. Res. Applic* **23**: 493–510.
Harby A, Olivier JM, Merigoux S, Malet E. 2007. A mesohabitat method used to assess minimum flow changes and impacts on the invertebrate and fish fauna in the Rhone River, France. *River Research and Applications* **23**: 525–543.
ICES. 2008. Report of the Baltic Salmon and Trout Working Group (WGBAST), 11 - 20 April 2007, Vilnius, Lithuania. ICES CM 2007/ACFM:12.
Johansen M, Elliott JM, Klemetsen A. 2005. Relationships between juvenile salmon, Salmo salar L., and invertebrate densities in the River Tana,Norway. *Ecology of Freshwater Fish* **14**: 331–343.
Jokikokko E. & Jutila E. 2004. Divergence in smolt production from the stocking of 1-summer-old and 1-year-old Atlantic salmon parr in a northern Baltic river. *J. Appl.*

Ichthyol **20**, 511–516.
Klemetsen A, Amundsen P-A, Dempson JB, Jonsson B, Jonsson N, O´Connell MF & Mortensen E. 2003. Atlantic salmon Salmo salar L., brown trout Salmo trutta L. and Arctic charr Salvelinus alpinus (L.): a review of aspects of their life histories. *Ecology of Freshwater Fish* **12**: 1–59.
Lamouroux N & Cattaneó F. 2006. Fish assemblages and stream hydraulics: Consistent across spatial scales and regions. *River Res.Applic.* **22**: 727–737.
Lamouroux N & Jowett IG. 2005. Generalized instream habitat models. *Can. J. Fish. quat. Sci.* **62**: 7–14.
Lamouroux N, Capra H. 2002. Simple predictions of instream habitat model outputs for target fish populations. *Freshwater Biology* **47**: 1543–1556.
Leonardsson K. 2010. Personal communication based on ArcGIS analyses of field based habitat mapping results in River Vindelälven. Department of Wildlife, Fish and Environmental studies. Swedish University of Agricultural Sciences. Umeå, Sweden.
Lundqvist H, Rivinoja P, Leonardsson K, McKinnell S. 2008 a. Upstream passage problems for wild Atlantic salmon (Salmo salar L.) in a regulated river and its effect on the population. *Hydrobiologia* **602**: 111-127
Mäki.Petäys A & Vehanen T. 2000. Microhabitat Use by Age-0 Brown Trout and Grayling: Seasonal Responses to Streambed Restoration under Different Flows. *Transactions of the American Fisheries Society* **129**:771–781.
Mäki.Petäys A, Erkinaro ., Niemelä E, Huusko A & Muotka T. 2004. Spatial distribution of juvenile Atlantic salmon (Salmo salar) in a subarctic river: size-specific changes in a strongly seasonal environment. *Can. J. Fish. Aquat. Sci*. **61**: 2329–2338.
Mäki.Petäys A, Huusko A, Erkinaro J & Muotka T. 2002. Transferability of habitat suitability criteria of juvenile Atlantic salmon (Salmo salar). *Can. J. Fish. Aquat. Sci.* **59**: 218–228.
McKinnell S M & Karlström Ö. 1999. Spatial and temporal covariation in the recruitment and abundance of Atlantic salmon populations in the Baltic Sea. *ICES Journal of Marine Science* **56**: 433–443.
McKinnell SM. 1998. Atlantic salmon (Salmo salar L.) life history variation: implications for the Baltic Sea fishery. *Doctoral Thesis, Department of Aquaculture, Swedish University of Agricultural Studies, 901 83 Umeå, Sweden*.
Milner NJ, Elliott JM,. Armstrong JD, Gardiner R, Welton JS. & Ladle M. 2003. The natural control of salmon and trout populations in streams. *Fisheries Research* **62:** 111–125.
Molin, J. 2008. Linking habitat characteristics and juvenile density to quantify *Salmo salar* & *Salmo trutta* smolt production in River Sävarån, Northern Sweden. Examensarbete 30 hp. Ht-2007. Institutionen för Vilt, Fisk och Miljö, Sveriges Lantbruksuniversitet (SLU), 901 83 Umeå. Accessed 09-03-24 at: http://ex-epsilon.slu.se/archive/00002401/01/2008_3_Johan_Molin_exjobb.pdf
Mouton A, Meixner H, Peter L, Goethald M, De Pauw N & Mader H. 2007. Concept and application of the usable volume for modeling the physical habitat of riverine organisms. *River. Res. Applic.* **23**: 545–558.
Murphy B.R. & Willis D.W. (1996). Fisheries techniques, 2nd edition. American Fisheries Society. ISBN: 1-888569-00-X.
Naturvårdsverket 2003. Handledning för miljöövervakning, Undersökningstyp: Biotopkartering – vattendrag 1 Version 1: 2003-06-17. (In Swedish). Available at: http://www.naturvardsverket.se/upload/02_tillstandet_i_miljon/Miljoovervakning/undersokn_typ/sotvatten/biotopkart.pdf

Nilsson C, Lepori F, Malmqvist B, Törnlund E, Hjerdt N, Helfield JM, Palm D, Östergren J, Jansson R, Brännäs E, Lundqvist H. 2005. Forecasting environmental responses to restoration of rivers used as log floatways: an interdisciplinary challenge. *Ecosystems* **8**: 779-800.
Östergren J. 2006. Migration and genetic structure of *Salmo salar* and *Salmo trutta* in northern Swedish rivers. *Doctoral Thesis* **2006:112**. ISSN: 1652-6880. ISBN: 91-576-7261-X, Department of Aquaculture, Swedish University of Agricultural Studies, 901 83 Umeå, Sweden.
Palm D. 2007. Restoration of streams used for timberfloating : egg to fry survival, fry displacement, over-wintering and population density of juvenile brown trout (Salmo trutta L.) *Acta Universitatis Agriculturae Sueciae* **2007:120**. Department of Wildlife, Fish, and Environmental Studies, Swedish University of Agricultural Sciences (SLU). 901 83 Umeå, Sweden
Perä I. 2006. Kartering av reproduktionsarealer för lax i vattendrag i Norrbotten och Västerbotten.Fiskeriverket rapport. Utredningskontoret Luleå. **2006-05-16** (In Swedish).
Rappe C., Ranke W., Soler T., Funegård P., Karlsson L. & Thorell L. (1999) *Baltic salmon rivers – status in the late 1990s as reported by the countries in the Baltic Region*. International Baltic Sea Fishery Commission (IBSFC) and Baltic Marine Environment Commission - Helsinki Commission (HELCOM) in co-operation with the Swedish Environmental Protection Agency and the Swedish National Bord of Fisheries. Göteborg: Göteborgs Länstryckeri.
Rivinoja P, Carlsson U. 2008. Miljöövervakning av lax i Västerbotten - Effekter av laxutplantering i Öre- och Lögdeälven under femton år. Rapport **59**, ISSN 1101-6620, ISRN SLU-VBI-R--59--SE Institutionen för Vilt, Fisk och Miljö 901 83 Umeå. (In Swedish). Available at: http://publikationer.slu.se/Filer/FinalLAXrapport59rev.pdf
Rivinoja P, McKinnell S, Lundqvist H. 2001. Hindrances to upstream migration of Atlantic salmon (Salmo salar) in a northern Swedish river caused by a hydroelectric power-station. *Regulated Rivers: Research and Management* **17**: 101–115.
Rivinoja P. 2005. Migration Problems of Atlantic Salmon (Salmo salar L.) in Flow Regulated Rivers. *Doctoral dissertation*. SLU, 901 83 Umeå. ISSN: 1652-6880. ISBN: 91-576-6913-9.
Romakkaniemi A, Perä I, Karlsson L, Jutila E, Carlsson U, Pakarinen T. 2003. Development of wild Atlantic salmon stocks in the rivers of the northern Baltic Sea in response to management measures. *ICES Journal of Marine Science* **60**: 329–342.
Rosenfeld J. 2003. Assessing the Habitat Requirements of Stream Fishes: An Overview and Evaluation of Different Approaches. *Transactions of the American Fisheries Society* **132**: 953–968.
Serrano I., Rivinoja P., Karlsson L. & Larsson S. (2009). Riverine and early marine survival of stocked salmon smolts, *Salmo salar* L., descending the Testebo River, Sweden. *Fisheries Management and Ecology*, Vol. 16, No. 5. pp. 386-394.Uusitalo L, Kuikka S, Romakkaniemi A. 2005. Estimation of Atlantic salmon smolt carrying capacity of rivers using expert knowledge. *ICES Journal of Marine Science* **62**: 708-722.
Strothotte E, Chaput GJ† & Rosenthal H. 2005. Seasonal growth of wild Atlantic salmon juveniles and implications on age at smoltification. *Journal of Fish Biology* **67**: 1585–1602.
Wikman-Myrestam D. 2010. Kvantifiering av laxhabitat: jämförelse mellan olika metoder. En fallstudie i Vindelälven , norra Sverige. Examensarbete 30 hp. 2010 (in press). Institutionen för Vilt, Fisk och Miljö, Sveriges Lantbruksuniversitet (SLU), 901 83 Umeå (In Swedish).