Master's thesis

Connections between microhabitat factors and dimensions of brown trout (*Salmo trutta*) redds

Faiqa Atique

University of Jyväskylä

Department of Biological and Environmental Science

International Aquatic Masters Programme

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University of Jyväskylä, Faculty of Science

Department of Biological and Environmental Science
International Aquatic Masters Programme

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ABSTRACT

This study is part of a process of habitat restoration and management of Finnish and Swedish rivers. This study was conducted to analyse detailed and generalised data regarding microhabitat factors and dimensions of spawning redd of brown trout (*salmo trutta*). The objectives of this study were to analyse connections between redd dimensions, connections between redd length and microhabitat factors and to analyse the variability of redd length and microhabitat factors among catchments in order to understand spawning habitat selectivity of brown trout (*salmo trutta*). The study shows that the redd dimensions are positively and strongly correlated. Redd length is weakly correlated to microhabitat factors: Redd length correlates positively to dominate and sub dominate particle size category in pot but does not correlate with dominate particle size category upstream from pot. Microhabitat is catchment specific. If I assume redd length as a proxy of fish size it can be speculate that not only fish size influence fish choice for spawning microhabitat but also other factors are involved. Modeling regarding redd dimensions and spawning microhabitat factors can be helpful to improve strategies for habitats restoration process.

Finnish abstract:

JYVÄSKYLÄN YLIOPISTO, Matemaattis-luonnontieteellinen tiedekunta

Bio- ja ympäristötieteiden laitos
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Hakusanat: kuteva habitaatti, mikrohabitaatti valinta, Pesän dimensio, *salmo trutta*, vaihtelu valuma-alueilla, yhteys.

TIIVISTELMÄ

Tämä tutkimus on osa suomalaisten ja ruotsalaisten jokien kunnostushanketta. Tutkimuksessa analysoidaan taimenen (*Salmo trutta*) kutupesien ja niiden mikrohabitaatin dimensioiden välisiä yhteyksiä sekä vertaillaan dimensioita eri vesistöjen välillä. Pesän dimensiot korreloivat voimakkaasti keskenään. Pesän pituuden ja mikrohabitaatin dimensioiden, mm. pesäkuopan yleisin ja toiseksi yleisin partikkelikokoluokka, välillä havaittiin heikompia korrelaatioita. Mikrohabitaatin dimensioissa havaittiin suuruuseroja vesistöjen välillä. Jos oletetaan, että pesän pituus on kalan koon indeksi, voidaan päätellä, että kalan kutuhabitaatin valintaan vaikuttaa kalan koon lisäksi myös muita tekijöitä. Tulosten perusteella voidaan ymmärtää paremmin kalan kutuhabitaatin valintaa ja kehittää ympäristökunnostuksia.

Contents

1. INTRODUCTION

Restoration of spawning areas is a common trend in several European countries. In Finland stream channel restoration has been going over 30 years. During the first half of 20th century forest industry grew strongly in Finland. Due to exploitation of forest resources, timber transportation increased and many water resources were exploited. Timber transportation network was expanded during 1950s and 1960s and resulted in more degraded habitats. The restoration work was mainly done for channels that were mainly degraded by timber floating, lake surface level lowering, forest and field dehydration, mills and sawmills construction (Muotka and Syrjänen 2007, Syrjänen and Valkeajärvi 2010).

Due to dredging, large proportion of bottom gravel was flushed downstream into pools and river mouths and the retention capacity of channels was weakened. Finnish streams were mainly restored for fisheries especially for salmonids, which usually spawn in riffle sections of streams. The goal of this restoration work was to improve natural reproduction of salmonids. For improved spawning channels in stream restoration, gravel is very often transported from a gravel pit and added to channel to create spawning grounds for salmonids (Muotka and Syrjänen 2007, Syrjänen and Valkeajärvi 2010).

Migratory brown trout *Salmo trutta* and resident brown trout stock are considered endangered in inland Finnish waters (Rassi *et al.* 2010). The basic reason for fish scarcity in Finnish watercourses is high fishing pressure in lakes and Baltic coast (Rassi *et al.* 2010, Syrjänen *et al.* 2014). The other reasons include river damming and dredging for log floating (Muotka and Syrjänen 2007, Syrjänen and Valkeajärvi 2010).

Declining number of migratory and resident spawners draw attention of fisheries authorities and managers to restore salmonids diversity (Muotka and Syrjänen 2007, Syrjänen and Valkeajärvi 2010). Different measures have been taken into consideration to restore diversity of salmonids. Restoration attempts, like channel restoration, and fish way building are mainly done to restore migratory trout diversity (Svensson 2012).

Stocking has been used mainly in past years. Stocking has been successful for population enhancement of salmonids in some rivers but not in all rivers. One of the reasons for less successful stocking in some rivers might be that hatchery-reared fish are aggressive and can displace wild fish in nature. Hatchery reared fish can affect genetic traits of wild fish and transfer diseases to wild stock when together in nature. But on the other hand hatchery reared fish are prone to risks especially, when limited supply of food in nature and can be less successful in reproduction (Jonsson and Jonsson 2011). Therefore, habitat restoration and enhancement should be preferred over other techniques (Jonsson and Jonsson 2011). Further research and knowledge are required about selection of fish spawning habitat (Svensson 2012). By the advancement of conservation biology, genetics, ecology and technology, researchers realize the importance of habitat restoration and adaptive management. Few modeling attempts have been taken to explain microhabitat factors alone. For example (Korsu *et al.* 2010) used hydraulic modeling approach to evaluate affectivity of restoration for invading species but no published studies are found to show how microhabitat and spawning redd connect to each other, which could be used in restoration of the spawning areas of salmonids.

1.1. Redd dimensions and microhabitat

Redds are gravel nests where salmonids spawn. Redd has two parts: redd pot and tail from upstream to downstream direction. Redd dimensions are horizontal and vertical measurements of redd. Redd dimensions are explained in detail in Figure 4.

Microhabitat for brown trout is a small scaled specialized spawning habitat within a larger habitat, which typically refers to the zone in which the brown trout spawn and where it can find shelter, protection and mates for reproduction (Jonsson and Jonsson 2011). Salmonids have special preferences for microhabitat especially for current velocity, depth, gravel particles, percentage of fines (Jonsson and Jonsson 2011).

Crisp & Carling (1989) reported that redd tails correlates with spawner length. Correlations in redd tails and fish length are important in two ways: in some cases it becomes difficult to measure fish length directly i.e. in deeper water or in severe weather conditions. Calculating fish length by using redd dimensions makes it possible to estimate fish length easily. Secondly, fish size is important in choosing egg burial depth.

Studies show that right choice of variables like water depth, water velocity, gravel size and fine particles is critical for fish for better growth, spawning success and survival of the alevins afterward (Shirvell and Dungey 1983, Kondolf and Wolman 1993, Armstrong *et al.* 2003, Morbey and Hendry 2008, Nika *et al.* 2011). Svensson (2012) also reported that current velocity and depth affect spawning probabilities of fish. Studies show that salmonids have preferences for some variables and it is important to know more about those variables that influence fish choice for spawning habitat (Shirvell and Dungey 1983, Kondolf and Wolman 1993, Nika *et al.* 2011). Further research is required to focus on wider perspectives regarding microhabitat because many parameters have direct impact on egg and fry survival (Sear *et al.* 2008). Gravel size is an essential factor for salmonids habitat because it affects the oxygen supply to eggs and alevins (Chapman 1988, Kondolf *et al.* 2008, Svensson 2012).

Substrate influences incubating eggs and survival of alevin's (Carling and Reader 1981, Carling 1984, Kondolf *et al.* 2008, Svensson 2012). But not much published information is available about habitat use of salmonid spawners in microhabitat or mesohabitat scale and importance of gravel restoration for spawners, incubating eggs, or emerging alevins (Carling and Reader 1982, Svensson 2012, Syrjänen *et al.* 2014). Syrjänen *et al* (2014) also pointed out the importance of gravel adding and ranking particle size in habitat restoration attempts. Substrate condition should be taken into account according to size of fish. For instance when gravelling river beds for salmonid juveniles, it is recommended to keep the amount of fines low, because embryo is sensitive to fine sediment infiltration during incubation period (Riley *et al.* 2006). High concentration of fines can degrade habitat for juveniles (Sergeant and Beauchamp 2006). Growth and size are the most important characteristics of fish because they are linked with fitness and survival of fish. Usually larger fish spawn larger eggs but perhaps it also depends upon temperature and oxygen contents of water (Lorenzen and Enberg 2002, Jonsson and Jonsson 2011).

Water velocity is another important factor. Different age groups of brown trout segregate in different habitats according to velocity, depth and cover in streams (Jonsson and Jonsson 2011). Young parr need shallow water with low current velocities. As they grow they prefer deeper areas and relatively higher velocities (Jonsson and Jonsson 2011). The absences of deeper area can constraint presence of large fish (Jonsson and Jonsson 2011). In early life stages of brown trout availability of slow flowing habitat is critical because it is difficult for small fish to hold their position in swift flowing water. Slow flowing habitats increase the chances of survival for alevins (Nislow *et al.* 1999, Armstrong and Nislow 2006). Current velocity affects the energy cost of spawning fish and fish speed to reach spawning area (Beechie *et al.* 2008, Svensson 2012). Water depth and velocity interact with each other and other factors like density, competition and presence of predators also influence habitat choice, thus to judge the habitat condition by single factor could be misleading (Jonsson and Jonsson 2011).

The distance of redd from hiding stone is important for spawners because they require more energy to cover longer distances (Jonsson and Jonsson 2011). Cover is an important factor for the growth and survival of salmonids and for choosing habitat. After emerging from redd alevins require cover; they search refuge in interstitial holes, tree trunks, under cut banks and in other vegetation like mosses etc. (Beland *et al.* 2004). When they grow they prefer to hold their position near a large stone or cobble particle (Jonsson and Jonsson 2011).

Seasonal variation i.e. light and temperature also affects growth, survival and habitat choice of brown trout. Photoperiod indicates season to fish and temperature controls biochemical and physiological reactions. Seasonal variation in light, temperature and flow can change their need for food and shelter. Competition in sympathy and physiological changes also results in partial segregation in habitat use (Haury *et al.* 1994). During winter parr prefer gravel and stony substrate because it helps them to hide and to reduce energy expenditure. In summer parr of brown trout are active during night and day (Gries *et al.* 1997, Imre and Boisclair 2004, Johnston *et al.* 2004, Breau *et al.* 2007). It is important to consider species, body size, and seasonal variation while restoring habitat for salmonids (Armstrong *et al.* 2003, Hendry *et al.* 2003, Mäki *et al.* 2004, Riley *et al.* 2006).

It is important concern to find association between redd dimensions and microhabitat factors. Regression modeling regarding these variables would be helpful for managers and restoration projects. It would be helpful to improve strategies for restoration projects and to avoid failure of conservation attempts. One of the reasons for failure of previous conservation projects was the use of non-optimal size of gravel. Hence it is important for fisheries managers to know particular requirements of particular species when dealing population enhancement.

Svensson (2012) also stated that currently we do not know what factors are connected to each other in selecting spawning habitat. There are few cases where the success of restoration has been evaluated, but we require knowledge to develop further better restoration strategies (Palm *et al.* 2007, Svensson 2012).

This lacking information is vital to conservation projects. Regression analysis considering microhabitat factors and redd dimensions must be helpful to anticipate the effect of one variable to another in order to understand the selectivity of brown trout for spawning habitat.

The main findings regarding connections between microhabitat factors and dimensions of salmonids redd in published literature reported in this thesis are presented below (Figure 1). There is not much information found in published literature about connections between redd dimensions and microhabitat factors, so these connections are missing in Figure 1. For planning and realization of habitat restorations it would be beneficial to find more information about the connections between redd dimensions and microhabitat factors.

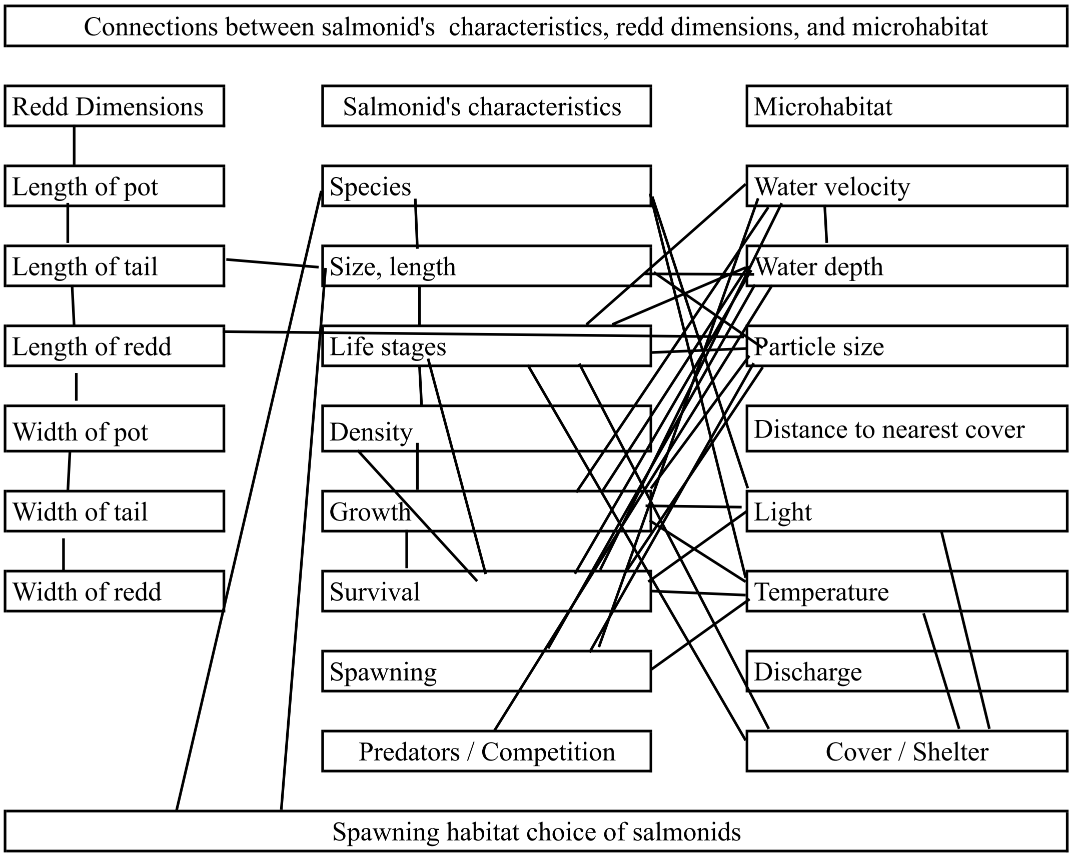


Figure 1. Connection between main characteristics of salmonids, redd dimensions and microhabitat factors that may have role in habitat restoration process. Lines show the connections (significant correlations) found in published literature reported in this thesis.

1.2. Aim of the study

The aim of the study is to find connections concerning redd dimensions and microhabitat factors. The main task of research was to answer the following questions:

1) Are there connections between redd dimensions?
2) Are there any connections between microhabitat factors?
3) Are there connections between redd length and microhabitat factors?
4) Is there any variation between catchments concerning redd length and microhabitat?
5) If the connections are found, what kind of they are?

The data used in this study was collected and recorded by Jukka Syrjänen, University of Jyväskylä, and his team from twenty-eight rivers and streams in Finland and Sweden, by using redd counting method in the years 2000–2014.

1.3. Redd Counting

Redd counting has been used for decades in some European watercourses and over 15 years in Finland for monitoring of fish spawning stock, management of streams and lakes (Dauphin *et al.* 2010, Syrjänen *et al.* 2014). Redd can be recognized as light area on substrate in streams. Redd count is fairly cheap method that allows valuable manifestation of the spawning stock of salmonids. Redd counts are considered as suitable indicator of spawning stock of salmonids. Redd dimensions and microhabitat factors are often measured in counting (Syrjänen *et al.* 2014). Redd counting can be done by using different methods, for example ground count and aerial count. The method used for data collection of this thesis is explained by (Syrjänen *et al.* 2014).

2. MATERIAL AND METHODS

2.1. Study area

Data were collected in Finland from the 14 rivers (Figure 2, Table 1) and in Sweden from the 14 rivers (Figure 3, Table 1). For river name, river number, river section, lake system and catchment area see Table 1. Data were collected in March–April for spring season. Data were collected for Spawning years 2008, 2009 and 2014 for spring. In autumn data were collected in October–December. In autumn data were collected for spawning years 2000–2014.

Table 1. Details of study area, sampling and data collection from Finnish and Swedish rivers.

River no.	Rivern name	River section	Lake system	Catchment area
1	Arvaja	Kivikoski	Isojärvi	Kymijoki
2	Brunnshyttebäcken	Section 1	Lundsfjärden	Götaälven
3	Gullspångsälven	Gullspångsforsen	Vänern	Götaälven
4	Heinävesi watercourse	Haapakoski, tanssilavan edusta	Kermajärvi	Vuoksi
5	Hjoån	Upstream from two new fishways	Vättern	Motala
6	Hjällöbacken	Upstream parts	Vättern	Motala
7	Hultabäcken	Section 1	Mullsjön	Motala
8	Juutua	Alakoski	Inarijärvi	Paatasjoki
9	Kalkkistenkoski	Kalkkistenkoski	Päijänne	Kymijoki
10	Kivijärvi watercourse	Huopanankoski	Vuosjärvi	Kymijoki
11	Klarälven	Side channel 1	Vänern	Götaälven
12	Knipån	Between 2nd & 3rd fishway	Vättern	Motala
13	Koivujoki	Lyytiskoski	Pielavesi	Kymijoki
14	Kuusinkijoki	Iso Vihtamutka	Pääjärvi	Koutajoki
15	Kärnä watercourse	Sahankoski	Keitele	Kymijoki
16	Könkköjoki	Könkönkoski	Karikkoselkä	Kymijoki
17	Läsänkoski	Keskikosket	Puula	Kymijoki
18	Muuramenjoki	Yläkoski	Päijänne	Kymijoki
19	Oulankajoki	Kiutaköngäs	Pääjärvi	Koutajoki
20	Partakoski	Partakoski	Saimaa	Vuoksi
21	Rautalampi watercourse	Siikakoski	Konnevesi	Kymijoki
22	Rutajoki	Matkus	Päijänne	Kymijoki
23	Small tributary river	Section 1	Mullsjön	Motala
24	Smedstorpsbäcken	Section 1	Vättern	Motala
25	Tidan Tributary 1	Section 1	Vänern	Götaälven
26	Tidan Tributary 2	Section 1	Vänern	Götaälven
27	Vaskojoki	Palokoski	Inarijärvi	Paatasjoki
28	Vindelälven	Nedre Harabacken	Storvindeln	Vindelälven

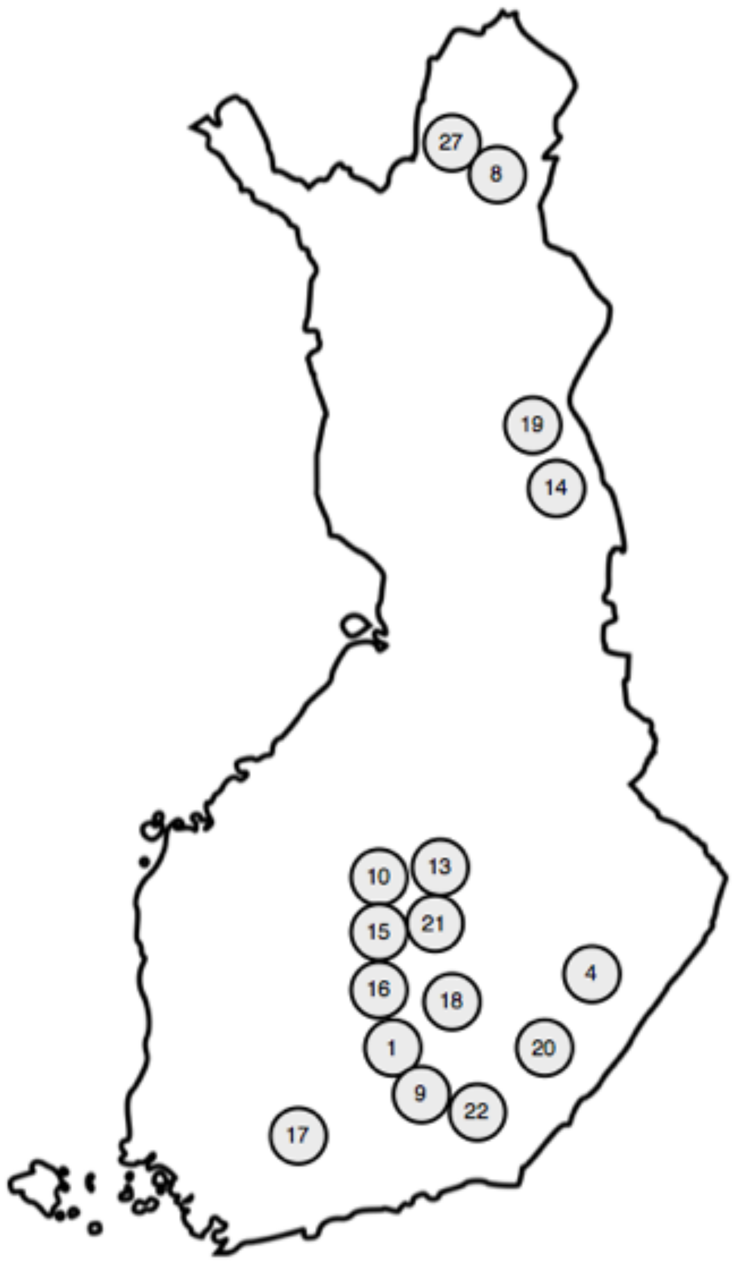


Figure 2. Location of Finnish rivers: for the name and further details about the rivers see Table 1.

Figure 3. Location of Swedish rivers: for the name and further details about the rivers see Table 1.

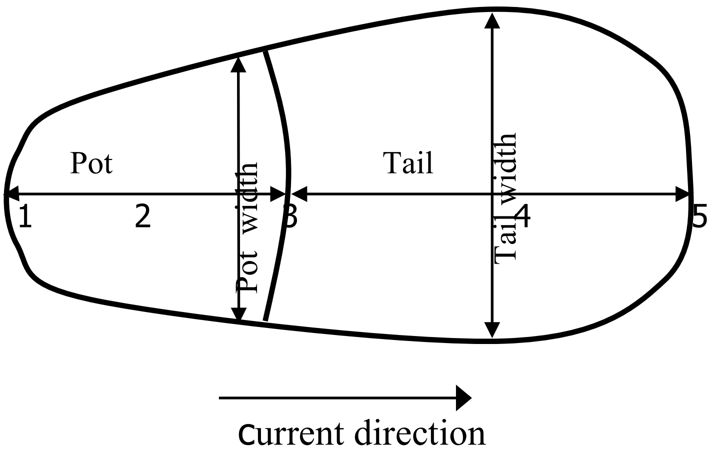
2.2. Sampling

Roughly 2000 redds were measured in redd counting by wading. Number of observation for different factors ranges from 1000 to 2000 because it was not possible to measure all of the factors in all redds due to severe weather conditions or lack of time (Syrjänen *et al.* 2014). Data were recorded carefully and all necessary precautions were taken into consideration. Data were labelled with spawning year, sampling date, catchment area, lake system, river and river section.

The redd data were mainly collected by Jukka Syrjänen, Kimmo Sivonen, Olli Sivonen, Jouni Kivinen and Mika Oraluoma from Finnish and Swedish rivers in the years 2000–2014. I learned techniques and methods to collect data for microhabitat factors and to measure redd dimensions in few Finnish streams and rivers in the year 2015 under the supervision of Jukka Syrjänen.

Riffle sections of streams or whole rapids were waded through completely. Sampling was done with aqua scope from bank to bank in an upstream direction to the water depth of 120 cm, deeper areas than that could not be sampled. If it was difficult to sample whole section, best spawning areas were inspected in order to find maximum number of redds. Unclear shaped pits were dug and checked for egg, if no egg were found they were rejected and not measured. Only clear redd shaped pits were considered as redd if they contained at least 1 egg. Details of the method are described in Syrjänen *et al.* (2014). Detailed redd dimensions and microhabitat measurements were recorded carefully by experts in all watercourses. Redd sites were observed by experts, so the estimation of redd dimensions, microhabitat factors and number of female spawners was reliable.

(a)



(b)

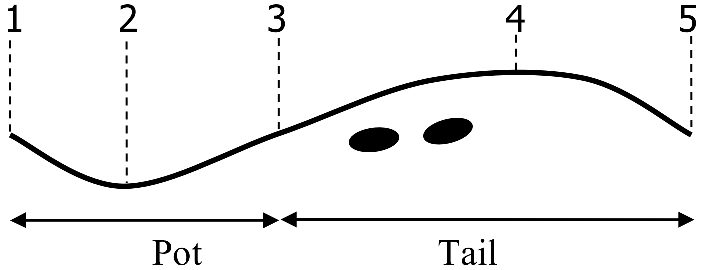


Figure 4. (a) Redd dimensions i.e. length and width of pot and tail. (b) Side profile of the spawning redd of salmonids. Five example points are shown, where depth and current velocity can be measured. 1 = upstream edge of pot, 2 = deepest point in pot, 3 = border between pot and tail, 4 = highest point in tail, and 5 = downstream edge of tail. The black oval bodies in tail represent egg pockets. Note: Figure published with kind permission of Jukka Syrjänen.

These redd dimensions were measured (Figure 4): pot length (cm), tail length (cm), total length of redd (The maximum total length of the redd (cm), i.e. the sum of the pot and the tail), pot width (cm), tail width (cm) and total width of redd (The maximum width (cm) out of the tail width and pot width).

The following microhabitat factors were measured: discharge (m^3s^{-1}) water depth (cm), water current velocity and distance travelled to nearest cover (cm). Five water depths were measured from points 1-5 as shown in Figure 4. Water velocity was also measured at five different points (1-5) (Figure 4). At every point (1-5) velocities were measured at different percentages of depth of the total depth: 20 % depth (From the water surface, i.e. quite near the surface), 60 % depth, 80 % depth, and bottom.

For statistical analysis best-suited velocity and depth were chosen. Velocities and depths from point 1-5 (Figure 4) were plotted against redd length to select most suitable depth and velocity for this statistical analysis. In this analysis those measurement points for velocity and depth were used that were best correlated to dependent variables.

In this study velocity at 60 % depth at point 3 (Water current velocity ($cm.s^{-1}$) in point 3 (upstream edge of pot), in the depth of 60 % of the total depth, just below the midpoint depth) was used. Depth at point 1 in redd (Figure 4) was used for this study. Depth at point 1 is the nearest point upstream from the pot; this point was best correlated to dependent variable.

Particle size was categorized according to modified Wentworth scale (Haggenes 1988). Dominate and sub dominant particle size at pot, tail and upstream from the pot was measured. Particle size was measured separately for pot and tail.

Other variables that were measured include: distances of redd from shore (The distance (cm) to the nearest channel bank or shoreline), distance from trunk (The distance (cm) to the nearest woody trunk or debris, that has the diameter of 10 cm or more), distance from hiding stone (The distance (cm) to the nearest stone or rock that is situated on the bottom with largest diameter 40 cm or more but above the bottom surface), total distance covered (The minimum value out of the three variables above, distance to the nearest cover).

2.3. Statistical Methods

The main statistical methods used in describing the data were frequency distributions, measures of central tendency and and measures of dispersion. The connections of variables were measured by Pearson's and Spearman's correlations. Two regression analysis were used to quantify relationship between redd tail and three horizontal dimensions of redd (Model 1), redd length and microhabitat factors (Model 2). Differences of means between groups were checked by using One-way ANOVA. The methods were chosen so that the statistical demands of the methods were met. The variables were transformed to natural log when it was necessary. The list of variables used and most important descriptive statistics are given in Table 2 and Table 3.

For Pearson correlation analysis normality of data was checked by histogram. Linear relationship between variables was checked by P-P plot and scatter plot between variables. If the relationship between variable was linear, Pearson's correlation analysis was conducted.

Spearman's correlation was chosen to find association between redd length and microhabitat factors, because data for particle size variables were categorical and ordinal (Table 3). The data for particle size were organised in 10 classes according to modified Wentworth scale (Haggenes 1988). The distribution of data for particle size was not normal. Monotonic relationship between variables was checked by matrix scatter plot. The relationship between variables was linear but data were categorical and ordered.

In order to estimate the quantitative relationship between redd tail and three horizontal dimensions of redd: length of pot, width of pot and width of tail linear regression analysis (Model 1) was conducted. For analysing quantitative relationship between redd length and microhabitat factors: velocity, distance travelled to cover and depth linear regression (Model 2) was conducted. For regression analysis, linearity of relationship was checked by analysing histogram and P-P plot. The assumption of homoscedasticity was checked by plotting graph between standardized residuals and standardized predicted values. Normality of variables was checked by histogram. Assumption for multi collinearity in multiple regression was checked by collinearity diagnostic test. Tolerance and VIF values were considered to check multi collinearity.

One-way ANOVA was used to compare means between catchment areas in order to find differences in redd length and microhabitat among catchments. Means for four variables: redd length, depth, velocity and distance travelled to cover were compared between six catchments. *Scheffe post hoc test* was used to compare means in catchments: Vindelälven, Motala, Kymijoki, Götaälven, Vuoksi, Koutajoki. Paatasjoki catchment was not compared because of lack of data in this catchment.

For one-way ANOVA normality of variables was checked by analysing Q-Q plots and histogram. Homogeneity of variance was checked by Levene's test. In this study sample sizes were not equal so *Scheffe post hoc test* was conducted. Variables were natural log transformed if necessary. All analysis were done by using software SPSS (version 21).

3. RESULTS

The measurement scale of data for Table 2 was ratio. Distribution of data was slightly skewed but not monotonic for variables shown in Table 2.

Table 2: Descriptive statistics for redd dimensions (Length of pot, length of tail, total redd length, width of pot, width of tail, total width of redd, Figure 4) and microhabitat factors (Depth (at point 1, Figure 4), velocity (at point 3 at 60 % depth, Figure 4), distance travelled to nearest cover and river discharge.

Descriptive Statistics						
List of variables	N	Range	Minimum	Maximum	Mean	Std. Deviation
Length of pot (cm)	2464	415	15	430	86.020	43.328
Length of tail (cm)	2720	435	15	450	120.014	61.744
Total length of redd (cm)	2720	780	30	810	203.100	97.484
Width of pot (cm)	2449	360	10	370	79.786	39.092
Width of tail (cm)	2468	385	15	400	86.866	42.544
Total width of redd (cm)	2663	385	15	400	90.888	44.391
Depth (cm)	2040	162	3	165	58.990	22.901
Velocity (cm/s)	1047	164	5	169	53.672	25.347
Distance to cover (cm)	1600	1600	0	1600	62.438	129.735
Discharge (m3/s)	15	19	1	20	3.310	5.235

Table 3: Descriptive statistics for particle sizes categories: Dominant particle size category from up stream, sub dominant particle size category from up stream, dominate particle size category from pot. Sub dominant particle size category from pot, dominant particle size category from tail, sub dominant particle size category from tail.

Descriptive statistics							
Variables measured (mm), in 1-10 categories in data	N (Valid)	Median (category)	Mode (category)	Range (category)	Minimum (category)	Maximum (category)
Dominant particle up stream	1703	6	6	9	1	10
Sub dominant particle up stream	1691	5	6	9	1	10
Dominant particle pot	2015	6	6	9	1	10
Sub dominant particle pot	1816	5	5	8	1	9
Dominant particle tail	2017	5	5	6	2	8
Sub dominant Particle tail	1817	5	4	7	1	8

All redd dimensions are significantly ($P < 0.01$) and positively correlated (Table 4). Total length of redd is highly correlated with total width of redd (Table 4).

Spearman's correlations between redd length and microhabitat factors (Other than distance to cover and dominant particle size category from up stream) are positive and significant but rather very low (Table 5). Spearman's correlation shows that total length correlates positively to dominant and sub dominant particle size category in pot, dominant and subdominant particle size category in tail but the level of correlation is not very high. The coefficient of determination is rather low (Table 5). Total redd length do not correlate with dominant particle category upstream from pot (The most abundant particle size just upstream from the pot) (Table 5). Distance to cover correlates negatively with depth and all categories of particle sizes but level of correlation is very low. In microhabitat factors velocity is most correlated to total length of redd (Table 5).

Regression analysis (Model 1, Table 6) shows that redd tail and three horizontal dimensions of redd can be predicted from each other with high accuracy. 62 percent variation in length of tail can be predicted by independent variables pot length ($p < 0.05$), tail length ($p < 0.05$) and pot width ($p > 0.1$).

In regression analysis (Model 2, Table 7) independent variables: distance travelled to cover ($p < 0.05$), velocity ($p < 0.05$) and depth ($p > 0.1$) have significant effect in model. But these microhabitat factors explain very low variation in redd length. Correlation coefficients are quite low. On average, microhabitat factors show almost same values for any size of redds (Table 7).

While comparing catchments there is significant difference in means of total redd length ($F = 108.339$, $p < 0.05$, Table 8), depth ($F = 117.794$, $p < 0.05$, Table 8), velocity ($F = 6.829$, $p < 0.05$, Table 8) and distance travelled to cover ($F = 19.811$, $p < 0.05$, Table 8).

In Vindelälven the redds were located in smaller water velocities than in Vuoksi and Koutajoki (*Scheffe post hoc test,* Figure 5a, Table 9). Longer distances to the nearest cover were travelled in Vindelälven. The means for distance to cover are second highest in Götaälven but the difference to e.g. Koutajoki is so small that it may be a random artefact. Least distances to nearest cover were travelled in Motala catchment; the reason might be the smaller size of Motala catchment (Table 10, Figure 5b). Redd were build at higher water depths in Vuoksi than in Motala catchments (Table 11, Figure 5c). Redd length was smaller in Kymijoki than in other catchments (Table 12, Figure 5d).

Table 4. Pearson's correlations between various redd dimensions (Total length of redd, length of tail, length of pot, total width of pot, width of tail, width of pot). Every variable is log-transformed.

Correlations							
		Total length of redd	Length tail	Length pot	Total width of redd	Width pot	Width tail
Total length of redd	Pearson Correlation	1	.952**	.893**	.783**	.746**	.777**
	N	2750	2750	2494	2693	2479	2498
Length tail	Pearson Correlation	.952**	1	.722**	.736**	.673**	.734**
	N	2750	2750	2494	2693	2479	2498
Length pot	Pearson Correlation	.893**	.722**	1	.734**	.733**	.708**
	N	2494	2494	2494	2479	2479	2479
Total width of redd	Pearson Correlation	.783**	.736**	.734**	1	.891**	.969**
	N	2693	2693	2479	2693	2479	2498
Width pot	Pearson Correlation	.746**	.673**	.733**	.891**	1	.827**
	N	2479	2479	2479	2479	2479	2479
Width tail	Pearson Correlation	.777**	.734**	.708**	.969**	.827**	1
	N	2498	2498	2479	2498	2479	2498

** Correlation is significant at the 0.01 level.

Table 5: Spearman's correlation between microhabitat factors: (Depth (at point 1, Figure 4), velocity (at point 3 at 60 % depth, Figure 4), distance travelled by fish to the cover and discharge), particle categories: (dominant particle category just upstream from pot, sub dominant particle category just upstream from pot, dominant particle category in pot, sub dominant particle category in pot, dominant particle category in tail, sub dominant particle category in tail) and total length of redd.

Correlations

Variables	Spearman's rho	Depth	Velocity	Distance to cover	Discharge	Particle up Dominant	Particle up sub dominant	Particle Pot dominant	Particle Pot sub dominant	Particle tail dominant	Particle tail sub dominant	Total length of redd
Depth	Correlation Coefficient	1	.167**	-.063*	0.028	.079**	.079**	.126**	.053*	.150**	.075**	.163**
	N	2070	1041	1540	15	1667	1655	1993	1769	1995	1770	2070
Velocity	Correlation Coefficient	.167**	1	.101**	0.527	.094**	0.052	.173**	.111**	.153**	.113**	.193**
	N	1041	1047	951	9	863	857	1012	864	1012	861	1047
Distance to cover	Correlation Coefficient	-.063*	.101**	1	-0.318	-.122**	-.057*	-.114**	-0.034	-.078**	-.078**	-0.04
	N	1540	951	1600	13	1366	1360	1528	1365	1528	1361	1600
Discharge	Correlation Coefficient	0.028	0.527	-0.318	1	0.118	-.926**	-0.15	-0.525	-0.025	-0.029	.547*
	N	15	9	13	16	6	6	12	6	12	6	16
Particle up Dominant	Correlation Coefficient	.079**	.094**	-.122**	0.118	1	.121**	.288**	.198**	.262**	.191**	-0
	N	1667	863	1366	6	1703	1691	1703	1700	1703	1698	1703
Particle up sub dominant	Correlation Coefficient	.079**	0.052	-.057*	-.926**	.121**	1	.227**	.330**	.290**	.293**	.103**
	N	1655	857	1360	6	1691	1691	1691	1688	1691	1687	1691
Particle Pot dominant	Correlation Coefficient	.126**	.173**	-.114**	-0.15	.288**	.227**	1	.180**	.437**	.233**	.242**
	N	1993	1012	1528	12	1703	1691	2045	1816	2045	1815	2045
Particle Pot sub dominant	Correlation Coefficient	.053*	.111**	-0.034	-0.525	.198**	.330**	.180**	1	.348**	.303**	.201**
	N	1769	864	1365	6	1700	1688	1816	1816	1816	1811	1816
Particle tail dominant	Correlation Coefficient	.150**	.153**	-.078**	-0.025	.262**	.290**	.437**	.348**	1	.202**	.222**
	N	1995	1012	1528	12	1703	1691	2045	1816	2047	1817	2047
Particle tail sub dominant	Correlation Coefficient	.075**	.113**	-.078**	-0.029	.191**	.293**	.233**	.303**	.202**	1	.133**
	N	1770	861	1361	6	1698	1687	1815	1811	1817	1817	1817
Total length of redd	Correlation Coefficient	.163**	.193**	-0.043	.547*	-0.001	.103**	.242**	.201**	.222**	.133**	1
	N	2070	1047	1600	16	1703	1691	2045	1816	2047	1817	2750

** Correlation is significant at the 0.01 level.

Table 6. Linear regression (Model 1) by using tail length as a dependent variable. Three predictor variables are: length of pot, width of pot, and width of tail. Every variable is log-transformed.

	Std. Coeff.		t	Sig.	Collinearity Statistics		R	Adjusted R Square	Durbin-Watson	F	Sig.	N
Variables	Beta	Std. Error			Tolerance	VIF						
(Constant)	.692	.064	10.879	.000			.788[a]	.621	1.784	1338.669	.000[b]	2449
Length pot	.396	.020	20.886	.000	.431	2.321						2449
Width pot	.005	.025	.218	.828	.275	3.635						2449
Width tail	.453	.025	19.886	.000	.299	3.350						2449

Table 7. Linear regression (Model 2) by using total redd length as a dependent variable. Three predictor variables are: velocity (at point 3 at 60 % depth) (Figure 4), depth (nearest point upstream from the pot at point 1 (Figure 4) and distance travelled by fish to the cover. Every variable is log-transformed.

Variables	Std. Coeff.		t	Sig.	Collinearity Statistics		R	Adjusted R Square	Durbin-Watson	F	Sig.	N
	Beta	Std. Error			Tolerance	VIF						
(Constant)		.238	16.487	.000			.271[a]	.068	1.307	14.292	.000[b]	545
Distance covered	.086	.021	2.033	.043	.955	1.047						545
Velocity	.223	.040	5.184	.000	.924	1.083						545
Depth	.052	.054	1.229	.220	.955	1.047						545

Table 8. One-way ANOVA to compare means of four variables: velocity (at point 3 at 60 % depth) (Figure 4), distance travelled by fish to the cover, depth (at point 1) (Figure 4) and total redd length between six catchments: Vindelälven, Motala, Kymijoki, Götaälven, Vuoksi, Koutajoki. Variables are natural log transformed.

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Velocity	Between Groups	8.955	5	1.791	6.829	.000
	Within Groups	273.019	1041	.262		
	Total	281.973	1046			
Distance to cover	Between Groups	89.469	5	17.894	19.811	.000
	Within Groups	802.063	888	.903		
	Total	891.533	893			
Depth	Between Groups	80.684	5	16.137	117.794	.000
	Within Groups	278.641	2034	.137		
	Total	359.326	2039			
Total length of redd	Between Groups	94.566	5	18.913	108.339	.000
	Within Groups	473.794	2714	.175		
	Total	568.359	2719			

Table 9. Post Hock showing Homogeneous subsets indicated by *Scheffe post hoc test* for natural logarithm of velocity (at point 3 at 60 % depth) (Figure 4).

velocity					
			Subset for alpha = 0.05		
Catchments		N	1	2	3
Scheffe[a,b]	Vindelälven	21	3.613		
	Motala	90	3.775	3.775	
	Kymijoki	728	3.842	3.842	3.842
	Götaälven	99	3.889	3.889	3.889
	Vuoksi	42		4.019	4.019
	Koutajoki	67			4.15
	Sig.		.16	.281	.076

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 55.076.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 10. Post hock showing homogeneous subsets indicated by *Scheffe post hoc test* for natural logarithm of distance travelled by fish to the cover.

Distance to cover					
			Subset for alpha = 0.05		
Catchments		N	1	2	3
Scheffe[a,b]	Motala	104	3.994		
	Kymijoki	583	4.056	4.056	
	Vuoksi	70	4.276	4.276	
	Koutajoki	17	4.461	4.461	
	Götaälven	93		4.691	
	Vindelälven	27			5.550
	Sig.		.362	.073	1.000

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 45.376.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 11. Post hock showing homogeneous subsets indicated by *Scheffe post hoc test* for natural logarithm of depth (at point 1) (Figure 4).

Depth						
			Subset for alpha = 0.05			
Catchments		N	1	2	3	4
Scheffe[a,b]	Motala	161	3.510			
	Koutajoki	76		3.747		
	Götaälven	143		3.884	3.884	
	Vindelälven	39			4.004	
	Kymijoki	1334			4.006	
	Vuoksi	287				4.350
	Sig.		1.000	.201	.330	1.000

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 106.691.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 12. Post hock showing homogeneous subsets indicated by *Scheffe post hoc test* for natural logarithm of total redd length.

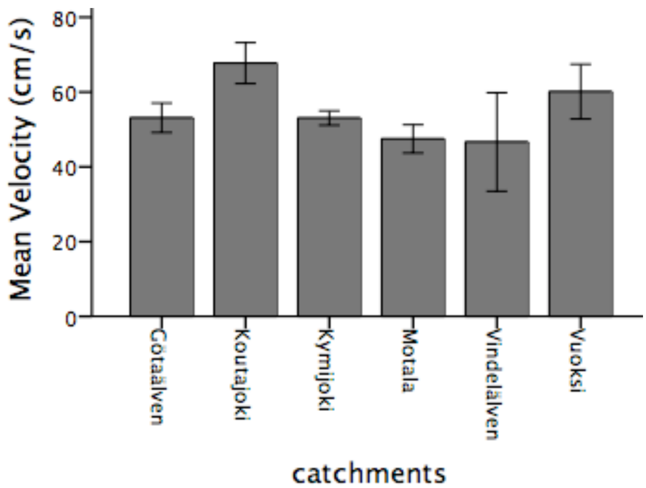
Total length of redd				
			Subset for alpha = 0.05	
Catchments		N	1	2
Scheffe[a,b]	Kymijoki	1792	5.075	
	Vuoksi	304		5.447
	Motala	230		5.464
	Koutajoki	76		5.475
	Götaälven	257		5.483
	Vindelälven	61		5.512
	Sig.		1.000	.888

Means for groups in homogeneous subsets are displayed.

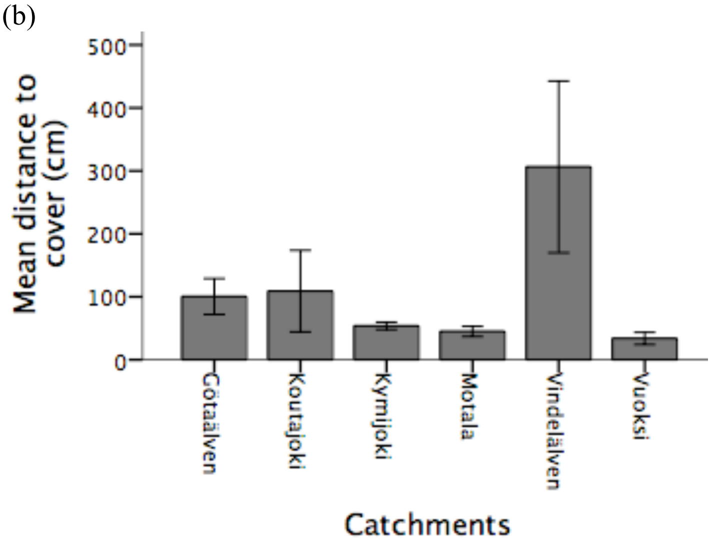
a. Uses Harmonic Mean Sample Size = 144.100.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

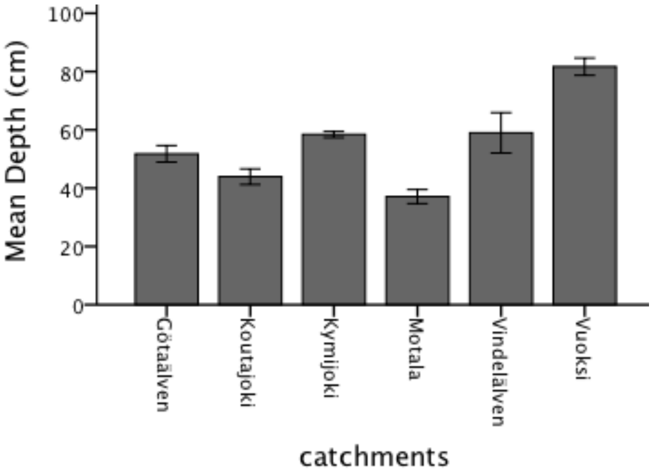
(a)



(b)



(c)



(d)

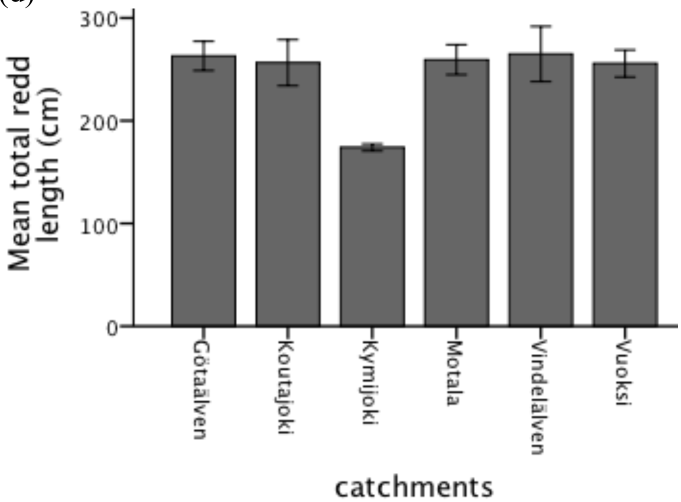


Figure 5. Plots of means to compare catchments a) velocity (at point 3 at 60 % depth) (Figure 4), b) distance covered to nearest hiding place, c) depth (at point 1) (Figure 4) and d) total redd length between six catchments. Error bars showing at 95% CI.

4. DISCUSSION

4.1. Redd dimensions

Four linear regression studies conducted by Crisp and Carling (1989) show relationship between three horizontal dimensions of redd and redd tail length. These regression analyses accounts 70% variance of each dependent variable and can be used to predict horizontal dimensions from one another (Crisp and Carling 1989). Crisp and Carling (1989) also found that generally larger fish make larger redd tail but smaller fish show more variation in making redd tails as compared to larger fish. According to Crisp and Carling (1989) fish size is important in choosing microhabitat for spawning and information about fish size can be the base for restoration projects.

The present study shows that three horizontal dimensions of redd and redd tail lengths are closely related to each other and can be predicted with high accuracy if some of them are known as suggested by Crisp and Carling (1989) (Table 6).

This research shows that longer redds have longer tails more height and more width as reported by Crisp and Carling (1989) (Table 4 & 6). If we assume redd length as a proxy for fish length, we can conclude that generally larger fish build longer redd as stated by Crisp and Carling (1989) (Table 4 & Table 6), although redd length does not impart much information about microhabitat selection by salmonids. It seems that they have much more flexibility in using microhabitat factors in relation to redd size. More information is required to understand how redd length and microhabitat selection for salmonids links to each other.

4.2. Particle size

Wollebaek *et al* (2008) stated that substrate particle sizes in the redd depression and tail were positively correlated with all redd size measurements except substrate in front of redd with redd depression length. This study also presents same results as stated by Wollebaek *et al* (2008) such as all particle size categories are positively correlated with redd length except most abundant particle size category just upstream from the pot (Table 5).

Assuming that redd length and fish size are positively correlated It seems that larger fish use bigger particle size when piling the tail (Table 5) and it can be considered that salmonids have preferences for gravel size depending on their body size, but it might also depends upon available particle size or other factors like available oxygen in water.

4.3. Velocity, depth, discharge and distance travelled to nearest cover

Correlation and regression analysis in this study show that longer redd were built at comparatively higher velocities in relatively deeper areas. Assuming that redd size represents fish size we can speculate that generally larger fish spawn in a bit faster current, at more depth (Table 5 & 7).

After spawning fish take refuge under hiding stone. Considering redd size as a proxy for fish size It can be speculated that generally larger fish might travel longer distance to nearest cover (Table 7).

The regression model 2 (Table 7) is weak and do not have much predictability. Further research is required to know better about fish choice regarding microhabitat factors like depth, velocity and distance travelled to nearest cover.

Assuming that redd length represents fish size, It seems that fish choice regarding these variables is not only fish size dependant but also other factors can be involved. It seems that fish travel distance depending upon availability of hiding stone or nearest cover regardless of fish size but It might also depend upon other conditions of river like flow, discharge and river size etc. (Table 5 & 7). Based on results it can be concluded that it is important for restoration process to put gravel beds on the sites near to hiding stone or the sites that seem to be close to salmonid's habitat choice.

Wolleback *et al* (2008) stated that microhabitat factors like velocity and depth correlate with each other. According to their studies water velocities and water depth explained most of the variation in choosing spawning habitat Wollebæk *et al.* (2008). Crisp and Carling (1989) also found that in general water velocities increase with increase in redd length, and velocity explains most of variation in redd length.

Present study shows same results: redd lengths are increasing with increasing velocities and depths as stated by Crisp and Carling (1989) and Wollebæk *et al* (2008). Velocities correlates stronger with redd length as compared to correlations for depth.

4.4. Variation among Rivers

Studies reported that microhabitat factors or suitable spawning habitat might vary between rivers or geographical areas (Calow and Petts 1994, Gurnell and Petts 1995, Rabeni and Sowa 1996, Payne and Lapointe 1997, Moir *et al.* 2004, Louhi *et al.* 2008, Svensson 2012).

According to Wolleback *et al* (2008) female size does not explain variation in redd length among rivers. It also depends upon other factors like substrate composition and particle size and local hydraulics. Redd length is comparable among rivers only if other environmental variable are constant which is not usually the case. Further more water velocity and depth also depends upon flow, discharge, river size and other environmental conditions. They stated that spawning habitat selection also depends upon availability of habitat variability.

Based on results in present study it seems that microhabitat is catchment-specific. If I compare microhabitat factors in Kymijoki to other rivers for instance in comparison with Motala catchment: In Motala catchment discharge and velocity are lower than in Kymijoki. Redd length in Kymijoki and Motala catchments are almost same even though the microhabitat factors in Kymijoki and Motala catchments are different. It can be concluded that microhabitat factors do not affect the redd length in Kymijoki catchment and there are some other factors that are affecting redd length in this catchment. If microhabitat does affects redd length the expected redd length should be longer in Kymijoki catchment because of its higher discharge and velocity as we know redd length correlates positively with the velocity and discharge (Table 5)| .The results are completely opposite than expectations, the possible explanation can be recreational fishing on lakes is strongest in the Kymijoki catchment. It can be concluded that migratory trout individuals do not survive back to spawn. Thus, the mean redd length is smallest in this catchment, as spawners are mainly resident and small-sized (Table 12, Figure 5d). It can be concluded that microhabitat factors do not explain much variation in redd length if environmental factors are not constant among catchments or it can also depends upon anthropogenic activities.

Water depths are smaller in Motala streams than all other catchments (flowing to Lake Vättern), the possible explanation can be that the rivers in this catchment are smaller than rivers in other catchments, discharge is also low in this catchment as compared to other catchments, so the smaller water depths are used for spawning in this catchment even the redd lengths are longer in this catchment (Table 11, Figure 5c). If we assume redd length represent fish size we can conclude that choice of fish for selecting spawning habitat also depends upon the availability of habitat or local conditions in rivers.

The long distances are travelled to nearest cover in Vindelälven, the possible reason might be that in Vindelälven catchment there were no bigger stones at spawning areas at all, so the fish had to travel longer distances or had to spawn without any hiding place (Table 10, Figure 5b).

Mean distance to nearest cover in Motala catchment is quite small. It can be concluded that the gravel beds should be placed near to stone, woody debris or channel bank in this catchment (Table 10, Figure 5b). Koutajoki is a big catchment and have higher discharge as compared to other catchments. In Koutajoki catchment more current velocities are used for spawning, the possible reason might be larger fish size in this catchment. Redd length is longer in this catchment; if we assume redd length as a proxy of fish size it can be concluded that larger fish prefer higher current velocities, but it might also depend upon other factors like higher discharge, flow and local conditions in this catchment. (Table 9, Figure 5a & 5d).

4.5. Conclusions

If we assume redd length as a proxy of fish size we can conclude that in general larger fish choose to build redd at higher velocities, deeper depths, choose bigger particle size for building redd and build redd at longer distances to nearest cover, but fish choice is flexible for choosing microhabitat and they can adapt according to local conditions and other factors. Particle size seems to be size dependant. It can be deduced that it is vital to consider optimum particle size when restoring rivers.

Based on results it can be concluded that microhabitat do not explain much variation in redd length among rivers and redd length can only be comparable among rivers if the environmental factors are constant. Fish choice in selecting microhabitat for spawning and building redd does not depend much on fish size but it greatly depends on factors like local river conditions, environmental factors and anthropogenic activities.

In habitat restoration projects this information can be used to find out and to restore spawning areas. Considering all factors like salmonids size, species, spawning habitat choice, local conditions of rivers can result in successful restoration work.

In a nut shell, in restoration attempts it is very important to consider factors like local conditions of rivers, anthropogenic activities and environmental factors beside considering fish size, species and preferences of salmonids for spawning habitat.

4.6. Need for further research

In order to develop better management plans further research is required in the field of fish genetics and environmental variables. It could be helpful to understand how environmental variability influence spawning habitat selectivity of salmonids in relation to their genetic flexibility to environmental factors.

Further modeling regarding variables like depth, river size, discharge, flow, distance to nearest cover could be helpful to further improve restoration strategies.

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