Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Natural Resources and
Agricultural Sciences

Barriers effect on lotic fish fauna

Barriärers påverkan på fiskfauna i rinnande vattendrag

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Independent Project in Biology (30 HEC) • Department of Aquatic Resources • Faculty of Natural Resources and Agricultural Sciences.

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Abstract

Barriers in running (lotic) waters are known to have serious impacts on fish fauna that would otherwise naturally colonialize them. The two most important effects barriers have on lotic fish fauna are the blockage of fish migration routes and the reduction of water velocity. These effects can in turn change the conditions for survival for species using lotic habitats. In this study I have investigated how barriers effect lotic fish fauna and whether the number of barriers blocking a river section from a migration pool is an important factor affecting these communities. To investigate this, a specially designed net, The Nordic multi-mesh Stream Survey Net (NSSN), for lotic watercourses was used to sample fish in the Swedish river Hedströmmen during July 2015. The number of species caught in the net was noted, the number of individuals per species counted, and in addition the body length was measured for European perch (*Perca fluviatilis*). In contrast to our predictions, number of species did not differ between unblocked and blocked sections in the river. However, there were differences in abundance (i.e. total number of individuals), although species differed in this respect. Seven out of the total eleven species were unevenly distributed between the two site categories (blocked and unblocked), in general showing a greater abundance in unblocked sites, thus following the predictions of this study. For European perch there were also differences in body length between the sites, with mean length being larger in blocked sites, proving different ecological implications depending on whether the site is obstructed or not. These results thus indicate that many fish species in lotic waters are affected by barriers.

Keywords: *Migration barriers, lotic fish fauna, Nordic multi-mesh Stream Net, abundances*

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1. Introduction

Human made barriers are known to have major negative effects on ecosystems in running (lotic) waters. Barriers block migration routes and slow down water movement, they modify the flora and alter the nutrient and carbon cycle (Baxter 1977; Ward and Stanford, 1983; Power et al., 1996; Peter, 1998; Jansson et al., 2000; Miyake & Akiyama 2012; Mims & Olden 2013). Many studies have shown that barriers in fresh water systems may have a negative impact on fish diversity, for example Robson et al., (2011) and Reidy Liermann et al., (2012). Barriers affect the fish fauna in many ways, but most importantly they inhibit migration and change the habitat from a fast flowing to a slow moving lake-type system.

Most fish species migrate to *forage*, *reproduce* or to *seek refuge* (Northcote 1978). Long distance migration however becomes impossible when barriers split up long, continuous water systems into many small sections and species that need to migrate long distances may go extinct (Andersson 1978a, b; Fukushima et al., 2007; Agostinho et al., 2008). The gene flow within these closed systems will also be limited, which in the long run can lead to inbreeding and loss of genetic diversity (Kitanishi et al., 2012; Livi et al., 2013). High genetic diversity is for many reasons important for a populations' survival. For instance, it is essential for a species' disease resistance and ability to adapt to environmental change (Detenbeck et al., 1992; Allendorf & Waples 1996).

Migration barriers affect fish species differently, e.g. depending on how far a species needs to migrate in order to find a suitable habitat to reproduce in. Species that migrate long distances, such as the catadromous European eel (*Anguilla anguilla*) and the anadromous Atlantic salmon (*Salmo salar*) are particularly affected. The barriers block these two species migration to their spawning habitats, which therefore results in a rapid decrease in their populations (Kottlelat & Freyhof 2007).

Obstructed areas in rivers affect fishes in more aspects than migration. For example, many fish species that live their whole life or a fraction of it in a river are dependent on high flowing habitats to be able to reproduce. Barriers slow down the movement of water, resulting in conditions more similar to a lake than flowing water. In these situations, sedimentation will occur at a greater rate, covering the hard substrate, such as gravel, which many fish species require for spawning. This effect can lead to a reduction in these unique spawning habitats, or even cause them to disappear entirely (Park et al., 2003, Degerman et al., 2013).

Species such as the northern pike (*Esox lucius*) spawn in flooded areas in spring, however today the majority of the rivers in Sweden are channelized. This reduces the time that flooding onto shallow vegetated areas can occur, which can result in fewer successful spawning seasons for northern pike. This in turn reduces the predation pressure on fishes in lower trophic levels and can disturb the ecological balance of lotic communities (Pershing et al., 2015).

One of the most common and widely distributed fish species in Sweden is European perch (*Perca fluviatilis*). This is mainly due to its ability to adapt to different environmental conditions. Holmgren et al., (2007) have introduced a method where the changes in ecosystem function in European perch is measured. Individual perch are rated on their potential as a piscivorous predator a scale of 0-100 percent. Fish receive a score of zero percent as a 'potential piscivor' before they reach a length of 120 mm. Thereafter they gradually increase their score as the amount of fish in their diet increases, to eventually become 100 percent 'potentially piscivorous' when a length over 180 mm is reached. With this concept considered, different length compositions of perch will result in different effects on the rest of the lotic community.

Due to the "slowing down effect" on the water induced by barriers in rivers, stream-adapted species like the brown trout (*Salmo trutta*), which is one of the few species that can colonize high velocity streams, will experience higher competition and be greater affected by predation from fish species that are adapted to slower water conditions. This will further enhance the switch from stream-adapted to lake-adapted fish fauna in obstructed rivers (Holden 1979; Degerman et al., 2013).

In Sweden inland water systems are highly affected by dams (Figure 1) as the vast majority (85 percent) of watercourses are used for hydropower (Svensk energi 2015). Migration through these barriers, i.e. passing through the turbine, is shown to induce high fish mortality (Greenberg et al., 2012; Calles et al., 2012). Today only 10 percent of Swedens' approximately 2100 hydropower plants are equipped with passages for the migration of fish from downstream sections (Näslund et al., 2013). Unfortunately, most of these fish passages are not well constructed, which means that only a limited number of the individuals that would normally pass the river section will find their way through the passage, as compared to if no barrier were present. Economic limitations often lead to the construction of sub-par fish passages which do not work effectively due to the weak water current they are most often designed to produce. It has been shown that fish preferably choose to swim against the strongest current, especially species in the Salmon (*Salmonidae*) family (Calles et al., 2013).

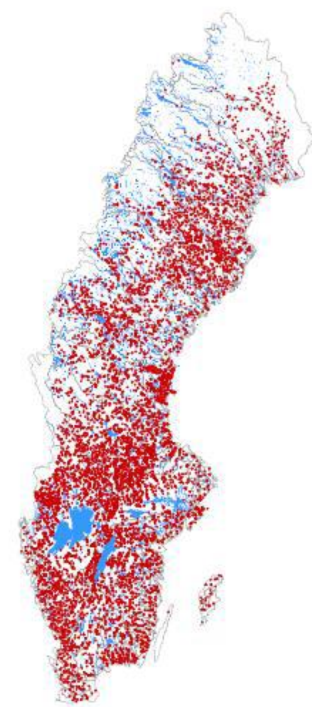

Figure 1. Dams in Sweden (SMHI dust files). Picture from Johan Kling, Marine and Water Authority.

Hedströmmen is a river in south central Sweden which has 12 hydropower plants and almost 80 dams blocking fish migration in its catchment area (Degerman et al., 2015). The river has its outflow in lake Mälaren and all species in the lake should theoretically have the possibility to migrate up into the river. In practice, species have different adaptations and requirements that increase or decrease the possibility of finding them in the river on a yearly or temporary basis. The ability for different species to survive in the river will change when barriers are added - for the better or worse. Species with essential needs to migrate long distances, such as the European eel (*Anguilla anguilla*) and the Atlantic salmon (*Salmo salar*) will be negatively affected by the creation of barriers. Furthermore, the length of river sections that are not dammed or canalized decreases when barriers are added to the river, which will in turn have negative effects on species that are bound to these sections for spawning, for example the brown trout (*Salmo trutta*) and the chub (*Leuciscus cephalus*). Species like white bream (*Abramis bjoerkna*) and rudd (*Rutilus erythrophthalmus*) that are favored in slow moving water should be positively affected by barriers in sections close to lakes, due to the barriers' 'slowing effect' on the watercourse. These slow water favored species were probably not present in river sections located far from lakes before artificial barriers were constructed, due to the unsuitably high rate of natural flow. Today these sections have favorable slow flowing conditions for these species to thrive but even so, they can't reach them due to the damming. Species like perch and roach are highly adaptable to various conditions as indicated by their wide distribution, which means that they generally will manage to reproduce in barrier blocked river sections. However, their reproduction can only be maximized if the possibility to migrate back and forth to a lake remains, as lakes often contain a greater diversity of vegetation which is rigid and complex in structure; a habitat in which, for example, European perch prefers to spawn in (Snickars et al., 2010). This should result in higher abundances of these species in the unblocked areas.

Species that should (under natural conditions) be native to the river Hedströmmen on a yearly or temporary basis and that have one or more barrier-vulnerable characteristics are listed in Table 1. These more vulnerable species are expected to be lower in number or absent in the most barrier-affected areas in the river.

Table 1. Species that should be native to the river Hedströmmen but also have characteristics that make them vulnerable to migration barriers. Compiled from Muus and Dahlström (1990) and personal communication with Arne Fjälling and Erik Degerman.

Species	Long distance migrator	Requires hard bottom substrate in lotic water
Trout	X	X
Salmon	X	X
Smelt	X	X
Ide	X	X
Asp	X	X
Chub	X	X
Vimba	X	
Eel	X	
Pike		X

Through the implemented EU Water Framework Directive, there is an urgent need to understand the ecological status of fish fauna in these heavily altered water systems (Swedish Agency for

Marine and Water Management 2014). In Sweden there is a standardized net survey method for lakes and a standardized survey method for electrical fishing for shallow flowing watercourses. For deeper sections in larger watercourses there is no standardized survey method yet. The aim of this study is to investigate how barriers affect lotic fish fauna and if whether the total number of barriers blocking a river section from a migration pool is an important factor affecting these communities. In this study, a specially designed net, The Nordic multi-mesh Stream Survey Net (NSSN), for lotic watercourses will be used in the Swedish river Hedströmmen (Fjälling et al., 2015). With the information from the previous research in mind, the following hypotheses have been established:

1). The total number of individuals for all species will decrease with increasing number of barriers that blocks fish migration back and forth from a migration pool, in this case Lake Mälaren.

2). The number of species will decline with an increase in migration barriers blocking a river section.

3). Species composition will differ between the sites depending on the number of barriers and various adaptations. For instance, lake favored species will be positively affected by the increased slow-water-conditions, but negatively affected by the blocking-effect of the barriers. Species that spawn in habitats that are present in flowing river sections and sections that are not canalized will be negatively affected. Species that are highly adaptable to different environmental conditions will still experience worse conditions for reproduction in barrier-blocked sections and will also therefore be negatively affected.

4). Two of the most common species in Sweden, perch and roach, will have a distribution throughout the whole river but in smaller numbers in the barrier-blocked sections because the migration routes to a lake with more suitable reproduction habitat are blocked.

5). A change in the fish species composition will allow the average length of perch to increase due to a reduction in other predatory species that are sensitive to lake like conditions. This in turn will lead to lower competition for European perch, which will ultimately create the potential for

European perch to become a large sized, top predator. Smaller European perch individuals will make up a larger proportion of the community in the sites that are less affected by barriers due to better conditions for reproduction (if the possibility to migrate back and forth to a lake still exists).

2. Material and methods

2.1 Study area

The study was performed in the county of Västmanland, in the river Hedströmmen and in lake Mälaren from the 6th to 22nd July 2015 (Figure 2, Table 2, larger sized map in Appendix). Hedströmmen has a catchment area of 1050 km^2 which is dominated by forest. The lower part of the river primarily flows through farmland and is cleared and straightened. The river substrate is mainly 'soft bottomed' and the majority of the river flows with slow velocity, although there are parts which flow faster (Degerman et al., 2015). The upper reaches have quite favorable conditions when it comes to shading and dead wood. The aquatic vegetation is diverse with no single dominant species (Johansson 2009).

Between the first and the last sampling site in this survey there are eight migration barriers and only the first (Kallstena hydropower plant) has a fish ladder (SMHI, dammregister, Figure 2).

Table 2. Days in the summer 2015 the different sites were surveyed, number of nets per site and number of nets per habitat in every site.

Site	Date	Total no nets	Nets in stream	Nets in deep	Nets in vegetation
Mälaren	10-12 July	22	0	11	11
Kallstena	13-16 July	32	9	17	6
Östtuna	17-20 July	32	13	11	8
Stora Forsby	21-22 July	15	0	7	8
Uttersberg	6-9 July	27	9	9	9

2.2 Choice of netting sites

The first sampling site, Lake Mälaren is connected to the outlet of Hedströmmen and was chosen as a reference site to Hedströmmen, i.e. to be able to see which species from the migration pool will disappear or show up dependent on how many barriers that are added. The second site, Kallstena, is the first river section and is located before the first migration barrier. This river section should not be affected by barriers since nothing disconnects it from Lake Mälaren and will therefore work as a control site within the river. The third sampling site, Östuna is the river section after the first migration barrier i.e. a hydropower plant equipped with a fish ladder and thus not a total barrier to fish trying to migrate from downstream to sections further upstream. Stora Forsby, the forth site is a section of the river behind the second barrier, which is a total block for fishes migrating from futher downstream as it does not have a fish ladder. The final site, Uttersberg is positioned far up in the river, with eight barriers between it and Lake Mälaren. The site has a lake (Lake Nedre Vättern) upstream of it, which is blocked by a barrier; an old mill which is no longer in use.

Table 3. Sample site characteristics

	Site	Coordinates (RT90)	Length (km)	Fish ladder	Dammed	Connected with Mälaren
1	Mälaren	X:6595152 Y:1514897	Lake	-	-	-
2	Kallstena downstream	X:6595207 Y:1510878	4,79	No barrier	No	Yes
3	Östtuna downstream	X:6594760 Y:1509421	1,5	Yes*	Yes	Yes*
4	Stora Forsby downstream	X:6594285 Y:1508903	7,62	No	Yes	No
5	Uttersberg	X:6625233 Y:1492141	1,33	No	Yes	No

*Fish ladder probably not used by all species (Calles et al., 2013).

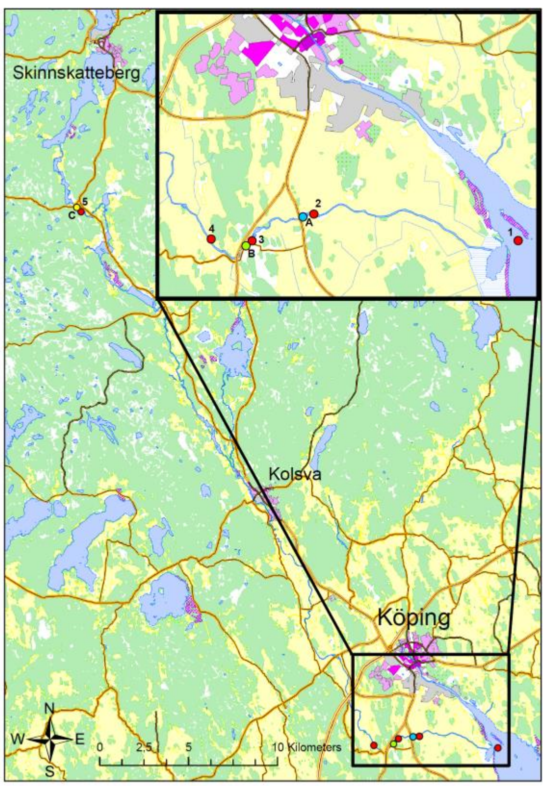

Figure 2. Study area. Red dots show surveyed sites in Mälaren (1), and Hedströmmen; Kallstena (2), Östtuna (3), Stora Forsby (4) and Uttersberg (5). Blue dot and A = the first barrier after Lake Mälaren, a hydropower station equipped with a fish ladder. Green dot and B = Second barrier, a hydropower station with no fish passage and yellow dot and C = the upstream barrier in the river section Uttersberg, an old mill. The river section between Stora Forsby and Uttersberg contains six barriers, but they are not shown on the map.

2.3 Sampling method

The surveying method used in this study was the Nordic multi-mesh Stream Survey Net (NSSN) which was specifically designed for investigating fish fauna in flowing waters (Fjälling et al., 2015). It is built similarly to the standardized Nordic survey net used in lakes (Kinnerbäck 2001) with identical mesh sizes in the 12 sections (mesh sizes from five to 55 mm divided on the sections) and with the separate sections arranged in a similar fashion. The net has a height of 900 mm but only reaches 700 mm into the water, due to its construction. The net is 18 m long (where every section is 1500 mm in length) with a total surface area of 12,6 m^2.

The nets were put into the water between 06-08 PM and brought up between 06-08 AM, which follows the Nordic net standardized method. For every individual that was caught, the species and the length were documented. The net was placed parallel to the watercourse (Figure 3) which lead to less material being entangled in the net and also reduced the degree to which the net was affected by the current.

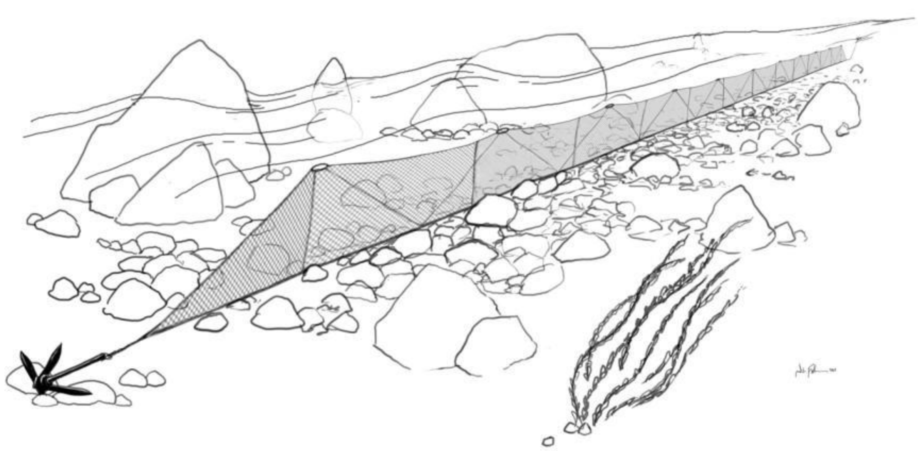

Figure 3. Stream survey net (NSSN) designed for investigating fish fauna in streaming waters (from Fjälling et al., 2012).

The nets were distributed in five different river sites, and within them the three most common habitats, i.e. fast flowing habitats, deep and slow flowing habitats and habitats that are dominated by vegetation (Table 2). Fast flowing habitats do not exist in Lake Mälaren and so were not measured. Eight nets were the minimum number of nets used per habitat in every site. The sampling effort in Stora Forsby was limited due to vandalism during the third night that the site was surveyed (Table 2).

2.4 Statistics

The association between abundance and sampling site was analyzed using four separate generalized linear models (Poisson distribution, log link) with number of fish individuals (all species, perch or roach) or the number of species as response variables. Only sites located in the stream were included in the analysis (Kallerstena, Östuna, Stora Forsby, Uttersberg) since the aim was to compare the effect of migration barriers in flowing water. The fixed factors were sampling site and habitat type. A similar model was used to analyze the relationship between perch length (mm) and sampling site. Pair wise comparisons between sampling sites located in the stream were made using Tukey's HSD test.

The analyses were performed in R 2.14.0 (R Development Core Team 2014) using the glm function for generalized linear models and the multicomp package (Hothorn *et al.,* 2008) for pairwise comparisons.

European perch length was also classified according to its 'piscivor potential' according to Holmgren et al., (2007).

Species composition was analyzed by categorizing each net as containing a species (1) or not containing a species (0). The binomial presence/absence response variable was analyzed using a chi-square test to investigate differences between sites. The test was carried out using IBM SPSS (version 22).

3. Results

In this study 142 nettings where made and within these nettings, 2243 individuals from 11 fish species were caught and identified (Table 5).

Table 5. Number of individuals of each species caught at the different sites.

Common name	*Scientific name*	Mälaren	Kallstena	Österttuna	S. Forsby	Uttersberg
Perch	*Perca fluviatilis*	352	90	42	21	70
Bleak	*Alburnus alburnus*	431	149	20	0	7
White bream/Bream	*Abramis bjorkna/brama*	287	11	0	0	6
Chub	*Leuciscus cephalus*	0	4	2	4	0
Ruffe	*Gymnocephalus cernua*	126	26	14	12	9
Pike	*Esox lucius*	1	1	2	1	1
Pike-perch	*Sander lucioperca*	12	1	0	0	0
Roach	*Rutilus rutilus*	238	90	111	47	157
Smelt	*Osmerus eperlanus*	8	0	0	0	0
Rudd	*Rutilus erythrophthalmus*	6	0	0	0	41
Bullhead	*Cottus gobio*	0	1	1	0	0

3.1 Abundance of individuals

The total number of individuals differed between the river sites ($Chisq_{3,\ 102}$=11.25, p=0.01, Figure 4 a). There was also a difference in perch and roach abundance between sites ($Chisq_{3,\ 102}$=11.12, p=0.01and $Chisq_{3,\ 102}$=29.79, p<0.001, respectively). Abundance of roach was higher in Uttersberg than in all other river sites (Figure 4 b).

The different habitats that was surveyed did not explain the variation in total number of individuals ($Chisq_{2,\ 100}$=5.311, p=0.07) or in the number of perch ($Chisq_{2,100}$=4.82, p=0.09) or roach ($Chisq_{2,100}$=6.96, p=0.05).

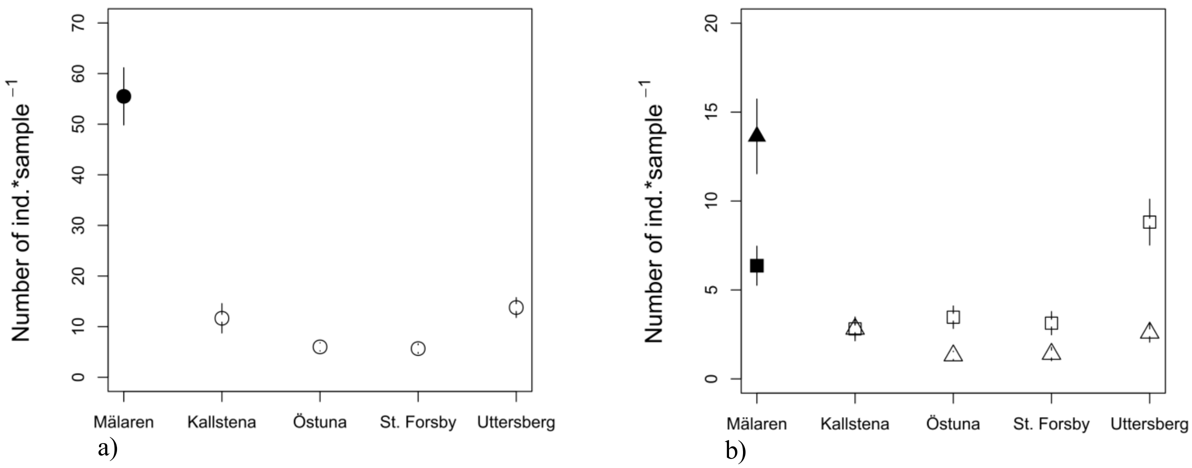

Figure 4. a) Mean number of individuals per sample in Lake Mälaren (filled symbols) and four sites in Hedströmmen (open symbols) with increasing number of migration barriers from Mälaren (from left to right) shown as a) all fish species and **b)** the most common species; perch (triangles) and roach (squares). The total number of individuals was higher in Uttersberg than in Östuna (p=0.02). Roach abundance was higher in Uttersberg than in all other river sites (Kallstena p<0.001, Östuna p<0.001 and Stora Forsby p=0.001), whereas perch abundance was higher in Kallstena than in Östuna (p=0.02). Bars show standard errors. Note the different values on the y-axis.

3.2 Number of species

There was no difference in number of species between sites in the river ($Chisq_{3,102}$=4.88, p=0.18, Figure 5) or between river habitats ($Chisq_{2,\ 100}$=3.03, p=0.22). In other words, the number of species in a site did not change with increasing barriers or distance from Lake Mälaren (Figure 5).

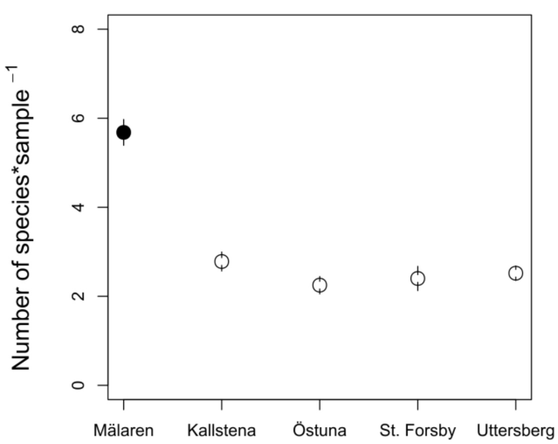

Figure 5. Mean number of fish species per sample in Lake Mälaren (filled circle) and four sites in Hedströmmen (open circles) with increasing number of migration barriers from Mälaren (from left to right). Bars show standard errors.

3.3 Size distribution of perch

3.3.1 Mean length

Perch mean length differed between the four sites in the stream ($Chisq_{3,\ 220}$=22.92, p<0.001, Figure 6 a). Perch in Östuna and Stora Forsby were on average larger than in the other stream sites (Figure 6 a).

3.3.2 Potential piscivor

The small size class (<120 mm, 0 % piscivor) was highest in Mälaren and decreased with distance from Mälaren and increased amount migration barriers, with an exception of Uttersberg (Figure 6b). The large size class (>180 mm, 100 % piscivor) showed the opposite pattern, with lowest proportion in Lake Mälaren and Uttersberg and the highest proportions in Östtuna and Stora Forsby (6b).

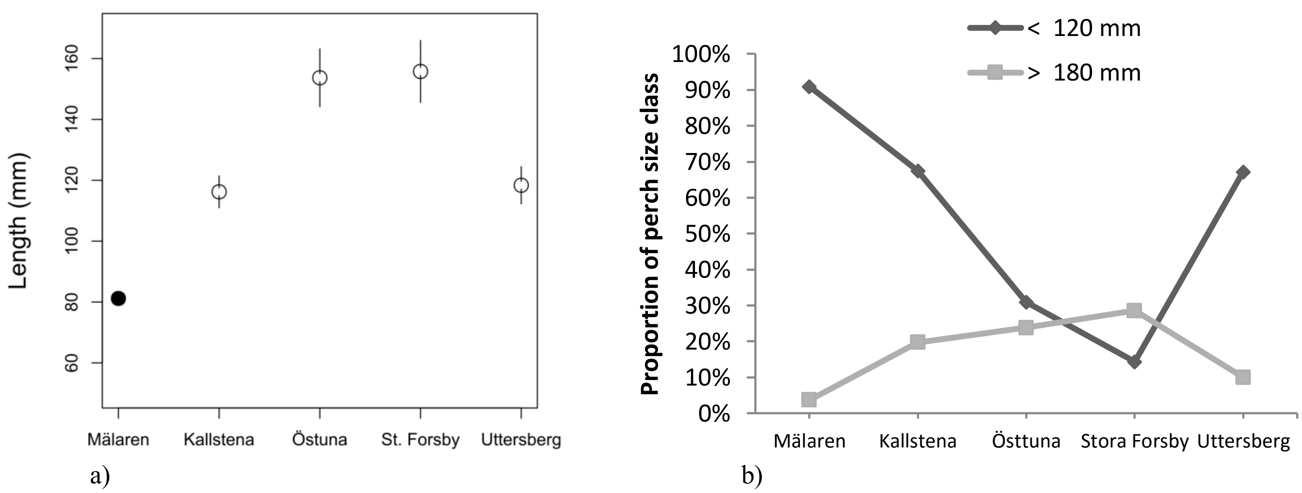

Figure 6. a) Mean perch length (cm) in Lake Mälaren (closed circle) and four sites in Hedströmmen (open circles) with increasing number of migration barriers from Mälaren (from left to right). Bars show standard error. Perch in Östuna and Stora Forsby were on average larger than in Kallstena (p<0.001 and p=0.01) and Uttersberg (p=0.002, P=0.02). **b)** Proportion of two different perch size classes. Size class < 120 mm = 0 % "potential piscivors", > 180 mm = 100 % "potential piscivors", a concept used by Holmgren et al., (2007) The two size classes shows opposite trends dependent on numbers of barriers disconnecting a site.

3.4 Species composition

We found an effect of the number of migration barriers on the distribution of seven of the eleven species (Table 6).

The presence of the slow water favored the species bream/white bream and rudd which were shown to be different between the sites (Table 6). Neither of the species was caught in Östtuna or Stora Forsby. The European perch showed a similar but weaker trend, with fewer present in Östtuna and Stora Forsby.

Bleak and ruffe were both shown to be differently distributed between the different sites, they were caught in every site except Stora Forsby (Table 6).

The European chub and the bullhead differed in presence between the sites, and none of them were registered in Lake Mälaren or Uttersberg (Table 6).

The presence of northern pike and roach did not differ between the sites, and they were caught in all sites (Table 6).

The pike-perch and the smelt presence differed between the sites, both were caught in Lake Mälaren, but only the pike-perch was caught in Kallstena (Table 6).

Table 6. The distribution (% nets with species present) of eleven species in lake Mälaren and four river sites in Hedenströmmen.

Common name	**Scientific name**	**Mälaren**	**Kallstena**	**Östuna**	**Stora forsby**	**Uttersberg**	**Chi-2**	**P (asymp.)**	**P (exact)**
White bream/Bream	*Abramis bjoerkna/brama*	95%	22%	0%	0%	15%	75,57	**>0.001**	>0.001
Bleak	*Alburnus alburnus*	91%	22%	22%	0%	12%	52,954	**>0.001**	>0.001
Chub	*Leuciscus cephalus*	0%	9%	6%	27%	0%	12,852	0,012	**0,01**
Rudd	*Rutilus erythrophthalmus*	18%	0%	0%	0%	23%	17,764	0,001	**0,001**
Roach	*Rutilus rutilus*	91%	88%	88%	87%	100%	1,811	0,771	**0,806**
Pike	*Esox lucius*	5%	3%	6%	7%	4%	0,541	0,969	**1,000**
European smelt	*Osmerus eperlanus*	23%	0%	0%	0%	0%	25,07	>0.001	**>0.001**
Bullhead (Millers thumb)	*Cottus gobio*	0%	3%	3%	0%	0%	2,032	0,730	**1,000**
Perch	*Perca fluviatilis*	95%	84%	66%	67%	77%	8,669	**0,070**	0,068
Pike-perch	*Stizostedion lucioperca*	36%	3%	0%	0%	0%	35,3	>0.001	**>0.001**
Ruffe	*Gymnocephalus cernuus*	82%	38%	31%	53%	31%	18,242	**0,001**	0,001

4. Discussion

In this project the number of species did not differ between the sites, instead species composition, individual abundance (including roach and perch abundance) and perch size composition differed between the sites. The overall pattern was that unobstructed sites had similar values to each other, and in turn obstructed sites also had similar values to each other. However, there were differences between these two different site categories in most of measured parameters. This shows that barriers have serious effects on the fish fauna that use river systems in July.

4.1 Barrier effect on abundance

The first conclusion one can draw is that Lake Mälaren has the largest abundance of all species, except roach. Lake Mälaren is the third largest lake in Sweden, and since there is a positive correlation between species abundance and lake area (Eadie & Keast 1984, Matuszek & Beggs 1988, Eckmann 1995), this result was expected. The larger a lake is, the greater the diversity of habitats, enabling more species and individuals to satisfy their essential needs and ecological niches. The results from Mälaren can be used as a reference value as to which species that have the potential to colonize the river, while the results from Kallstena work as a control site, which can be compared to the other sites to enable evaluation of barrier effects. The results from Kallstena is considered to be the most unaffected, because the site has no barriers disconnecting it from the large Lake Mälaren.

4.1.1 Total abundance

The total abundance of individuals in the surveyed sites differed, and the post hoc test revealed that Uttersberg had a significant higher abundance than Östtuna. According to my hypothesis Uttersberg should be the site with the lowest abundance of individuals. It is strange therefore that the first site, Kallstena, and the last site, Utttersberg, have similar mean abundances, both of which are also higher than the sites in-between (Östtuna and Stora Forsby). How can the last site which has the most barriers disconnecting it from the large migration pool, Lake Mälaren, have a similar total abundance as Kallstena? The most logic explanation to this unexpected result is that Uttersberg also is connected to a migration pool, the upstream Lake Nedre Vättern. This explanation is supported by the fact that a large number of the parameters measured in this project showed a similar pattern, where the results in Kallstena and Uttersberg were most similar to each other, and differed greatly to the results from Östtuna and Stora Forsby (which in turn had values which resembled each other). This means that the barrier between Uttersberg and Lake Nedre Vättern cannot be a total obstacle to fish migration. As mentioned earlier this barrier is an old mill in contrast to the other barriers blocking the surveyed sites, which are exclusively hydropower plants. This older barrier thus has less fish mortality factors, such as turbines (Greenberg et al., 2012; Calles et al., 2012) and protective grating (Russon et al., 2010). Fish from Lake Nedre Vättern can most likely migrate down to Uttersberg by moving through or bypassing the mill via canals without a high risk of injury. The increased fish migration from Lake Nedre Vättern down to Uttersberg increases the total abundance of fish, resulting in the site resembling the results collected at Kallstena, and therefore supporting higher abundance of individuals than the barrier-obstructed Östtuna and Stora Forsby. When considering that Uttersberg has a fish migration connection with a lake, the hypothesis is supported, that is to say that fish abundance in barrier affected sites is lower than sites where migration from lakes is possible.

4.1.2 Roach abundance
The abundance of roach was higher in Uttersberg than the rest of the river sites, again supporting the theory that migration from Lake Nedre Vättern to Uttersberg occurs, resulting in greater abundance of roach individuals. Given that roach abundance is even higher in Uttersberg than Kallstena, roach migration from Nedre Vättern to Uttersbeg seems to occur more frequently than migration from Lake Mälaren to Kallstena, perhaps due to the counter flow inhibiting fish migration from Lake Mälaren to Kallstena.

4.1.3 Perch abundance
The perch abundance was higher in Kallstena compared to Östtuna, which is in line with the predictions. There was also a weak trend illustrating Uttersberg to be similar in abundance to Kallstena, and higher than Östtuna and Stora Forsby, once again indicating a migration connection between Uttersberg and the lake upstream of the site.

4.1.4 Number of species
Species abundance did not differ between river sites or habitats. This result is not in line with my hypothesis, nor with other studies (Morita et al., 2002; Nislow et al., 2011) which have shown lower number of species in barrier blocked river sites. If data collection would have been performed in the autumn, instead of during summer as in this study, when many of the species from Lake Mälaren migrate up in rivers to spawn (for example asp, smelt and vimba) the species

abundance would most likely have been significantly higher at sites where fish migration from lakes occur. In our case the sampling period was in July, which primarily gives a picture of the fish fauna living in the river all year round. If no other parameters would have been measured in this project, the result that species abundance did not differ between sites would thereby give the picture that barriers do not affect fish fauna. If species are present at sites that are connected to a lake, and are absent in obstructed sites, this hints that these two 'site types' differ in their conditions. These differing conditions dictate which species that can fulfill their ecological needs and which cannot. If one species were to disappear, this might (through a process of 'ecological release') leave room for another species, resulting in similar species abundance between the sites but with different species composition, which will be discussed further in a subsequent section.

4.2 Barrier effect on perch size composition

As previously mention, European perch are one of the most common and widely distributed fish species in Sweden. This indicates a highly adaptive lifestyle considering Sweden's diverse climate and ecological conditions. The species' ability to transform from a small planktivor to a large sized piscivor (Holmgren et al., 2007) shows how large an impact its presence can have on freshwater communities, such as in lotic systems.

The mean length of European perch was significantly longer in the obstructed sites Östtuna and Stora Forsby than when compared to Kallstena and Uttersberg. This result once again provides further evidence that Uttersberg is connected to a lake, due to its striking similarity to Kallstena, which is itself connected to Lake Mälaren. The method developed by Holmgren et al., (2007) was used in this study to be able to see ecological differences in different perch size compositions. The small sized non piscivorous class had a negative correlation with increasing barriers, meaning that the proportion of the class is largest in Kallstena and then decreases as the number of barriers increases. This is of course except for Uttersberg, where the proportion was once again more comparable with Kallstena, providing further proof that fish migration occurs between the upstream lake Nedre Vättern and Uttersberg. The opposite pattern was shown for the large sized piscivor class, which appeared to have a positive correlation with number of barriers. The lowest proportion for the class was shown in Kallstena, which gradually increased with the number of barriers (except for Uttersberg, with results once again indicating similar conditions to Kallstena). If Uttersberg is considered to be a site where fish migration from a lake is possible, the perch length composition is in line with the hypothesis, i.e. that mean length is greater in barrier obstructed sites than in sites that are connected to a migration pool, and therefore that small sized individuals will be more abundant in river sites that are well connected to a lake. Why is the mean length greater in the barrier blocked sites and why are the proportion of individuals smaller than 120 mm ("100 % potential piscivor class") more abundant at connected sites? There are important differences between these kinds of barrier-blocked sites and the connected sites which limit the number of large sized predatory species like pike, brown trout, Atlantic salmon, asp etc. These species are often dependent on the opportunity to migrate long distances and/or the availability of suitable spawning habitats, which are highly limited in barrier blocked river systems (Näslund et al., 2013). As such these species cannot in most circumstances fulfill their essential needs for survival in these blocked river sites. These predators are important for maintaining 'balance' within the ecosystem, for example their function as a predatory control on the abundance of other species. When large sized predator species disappear from a water system, the predator control is released. It is then that European perch, which is a highly adaptive species, can take over the as the top predator. This is because competition and predation from other predatory species is no longer affecting the perch in the same magnitude, which allows perch to grow larger, and eventually take over the role as top predator (Pershing et al., 2015).

Why then are the mean perch length shorter and the proportion of individuals smaller than 120 mm (i.e. within the "0 % potential piscivors class") greater in sites where migration back and forth from a lake can occur? There are of course many factors that affect the perch size composition in a river site. One large difference is the ability for fish to migrate down to a lake. Vegetation is naturally more abundant in lakes than as opposed to rivers, due to greater nutrition, slower moving water etc. The vegetation present is also most often more rigid and more complex in its' structure, which are the conditions that perch prefer for spawning (Snickars et al., 2010). The larger abundance and appropriate condition of vegetation gives perch the opportunity to maximize their reproduction if they migrate to such sites. This is potentially one of the reasons why the proportion of small sized, most likely younger, perch individuals are in greater abundance at sites where the opportunity for migration still remains. In the barrier-blocked sites the abundance of appropriate spawning vegetation for perch is most likely lower, which could lead to lower rates of reproduction. The high abundance of vegetation in lakes also functions as refuges for young fish individuals. In rivers there are less of these refuge structures, which could potentially lead to a higher levels of predation on young perch by larger perch, who have taken over the top predator roll in these sites (Northcote, 1978).

4.3 Barrier effect on species composition

The rudd, white bream and bream are all species that favor habitats in nutrient rich slow flowing or stagnant waters (Muus and Dahlström 1990). The rudd was only caught in Mälaren and Uttersberg with white bream/bream also caught at these two locations, and also in Kallstena. These three sites had one thing in common; they are all connected to a lake in one way or another. Mälaren is itself a lake, Kallstena is connected with Lake Mälaren with no barrier to migration, and Uttersberg is considered to be connected upstream to Lake Nedre Vättern. This means that sites where fish migration to and from a lake is possible these lake-favoring species ecological needs are fulfilled, but when barriers to migration are present then these species cannot survive. The absence of these species in Östtuna shows that the fish ladder downstream of the site most likely does not work, and the presence of the species in Uttersberg suggests that the site is well connected to a lake.

European perch were not shown to be unevenly distributed between the sites but a weak trend showed a similar pattern as the previously mentioned species. The percentage of nets catching perch was 20 % higher in Kallstena than the barrier blocked sites and 10 % higher in Uttersberg, illustrating that this species is more common in sites where migration to and from a lake is possible, which indicates that this ability is important for the presence of perch.

The presence of bleak and ruffe were both shown to be unevenly distributed between the surveyed sites. The greatest difference in the abundance of these species was between Lake Mälaren and the river sites. Within the river sites the prevalence of these species was not significantly different, except for Stora Forsby where the numbers are less predictable due to the sabotage that happened at the site. Taking this into consideration, these species are most likely evenly distributed between the river sites. If the species were equally distributed in both barrier-blocked and connected sites this would show that they are not affected by barriers to migration.

Both chub and bullhead were not caught in Lake Mälaren or Uttersberg, showing an opposite preference as to the "slow water favored" species, which were only caught in sites connected to a lake. Indeed, chub and bullhead are both species that prefer to live their entire life in river systems (e.g. Kullander et al. 2012). The chub was caught in every river site except Uttersberg, perhaps indicating an effect of altitude. The highest percentage of nets that caught chub were from Stora Forsby. Stora Forsby should be a site that is highly affected by barriers and therefore it is interesting that this “river favored” species were most common there. One explanation could be that Stora Forsby was by far was the longest site, this perhaps reduces the effects of barriers and therefore the species can fulfill their ecological needs to a higher degree when compared to other sites of a more limited length.

Northern pike and roach were caught in all sites and their distribution between the sites did not differ. This indicates that these species are not affected by barriers. Interestingly, the conditions for roach appear to be more favorable in Uttersberg, where a greater percentage of nets caught the species. Perhaps this is due to good spawning conditions in the lake upstream of the site, which leads to a large abundance of roach which can migrate down into Uttersberg. Northern pike appear to be evenly distributed, but only a limited number of individuals were caught at every site. This could be a sign that the method of netting is not optimal for catching pike. Nearly all pike were caught close to smaller individuals, often with fish in their mouths. This indicates that pike are most often caught when trying to steal fish from the net.

Pike-perch were only caught in Mälaren and Kallstena, confirming the species to be absent in the blocked river sites. The species is known to prefer lake conditions, but at the same time it has been shown to migrate to rivers for reproduction purposes, e.g. Byälven in Lake Vänern (E. Degerman pers. corr.). This could mean that pike-perch abundance is enhanced by the occurrence of rivers. Indeed, pike-perch may even migrate between lakes via rivers (e.g. Kullander et al. 2012) with rivers providing populations with the opportunity to connect between lakes in order to maintain a high level of genetic diversity. In water systems where migration possibilities are limited this can, in the long term, result in loss of genetic diversity, which in turn can result in population extinction. This indeed could be the case for pike-perch populations living in the lakes connected to the highly obstructed river Hedströmmen.

4.4 Limitations and sources of error

It would have been desirable to test fish with the nets also in lake Nedre Vättern. However, from this lake there were already results from a test fishing carried out with the Nordic nets for lake surveys (NORS, 2015). It has been established that the new nets and the Nordic nets give similar catches (Fjälling et al. 2015). This means that it may be possible to compare our results with the test fishing in Lake Nedre Vättern. The results from NORS (2015) showed a dominance of roach. This strengthens the view that the fish fauna at Uttersberg was influenced by the upstream lake.

Certainly more information on the effects of the isolation caused by the dams could have been available if sampling had included genetics and age samples. However, this would have been very time consuming within the present project and was not included. Genetic sampling could have shown if the isolation at Stora Forsby had led to decreased genetic variation. Further this could have been used to strengthen the hypothesis of the direction of gene flow (and individuals) at Kallstena and Uttersberg.

Although the results from this study seem to show fish communities to be highly affected by migration barriers, other aspects should also be taken into consideration, for instance the length of the river sections. Clearly, the lengths of the sampling sites differ, from a minimum of 1,33 km in Uttersberg up to 7,62 km in Stora Forsby. This could affect the results, due to that the fact that a larger area of water should contain a greater species abundance than a smaller one (Eadie & Keast 1984, Matuszek & Beggs 1988, Eckmann 1995).

Consideration should also be given to the number of samples taken from Stora Forsby, since only 12 nets could be analyzed due to vandalism. This is of course a source of error that can reduce the reliability for the results from Stora Forsby. If the site length of Stora Forsby (by far the longest of the sites) is also considered, it can be concluded that 12 nets may not be enough to capture the 'full picture' of the fish community in Stora Forsby.

Furthermore, it is also important to take the study period into consideration, since all the sampling was performed in July. The results from this period thus only shows the fish community composition during a limited period of the year, and hence not the entirety of the species that are connected to the river throughout the whole year. For instance, smelt are a species that spawn in rivers during the spring (e.g. Kullander et al. 2012), whereas other species, such as the brown trout, migrate for reproduction during the autumn (e.g. Kullander et al. 2012). If the survey had been carried out in the autumn or in the spring perhaps many more species would have been caught, especially in the sites that are connected to the migration pools, and probably fewer species would have been caught in the barrier-obstructed sites. However, had the study been performed during the autumn season the Nordic multi-mesh Stream Survey Net (NSSN) would probably not have been an adequate surveying method, since too much additional material, such as leaves, would get caught in the net. This in turn would have affected the catching rate and the validity of the results.

5. Conclusions

The aim of this study was to investigate how barriers affect lotic fish fauna and whether the number of barriers blocking a river section from a migration pool is an important factor affecting these communities. The study showed various differences in fish fauna between river sections that were connected to a migration pool and sections where the possibility to migrate to a migration pool (Lake Mälaren or Nedre Vättern) was blocked. In order to ensure a fish fauna of high ecological status, similar to that of unaltered lotic waters, it is thus important to retain migration routes between river sections and migration pools. This knowledge is central for decision makers, since the new EU Water Framework Directive requires improvement of the ecological status in Swedish watercourses. In this study the fish ladder at Kallstena was shown to be inadequate at aiding fish migration upstream. This information, together with the results from Calles et al., (2013), which showed similar findings, justifies that other more natural fish passage alternatives, such as bypass channels (Noonan et al., 2012) or even the removal of barriers (Gardner et al., 2013) should be used in order to improve the ecological status of these streams.

In general, an increased number of barriers added after the first initial occurrence did not result in a greater effect on the fish fauna, rather it remained on a similar level. Thus, the study proves that it is the first barrier that has the greatest importance for how the lotic fish fauna is composed. The subsequent barriers mainly affected the length of a river section and therefore how many different habitats it contained. With more habitats, species adapted to lotic waters will have a greater opportunity to satisfy their essential ecological needs, resulting in higher ecological status. This in turn means that decision makers should consider leaving long river sections between barriers rather than short ones.

Even though the study shows that migration barriers clearly affects the lotic fish fauna, it is important to keep in mind that these results only portray the situation during one summer month. In order to attain a more complete picture, it is thus important to develop complementary methodologies that can be used in other periods of the year.

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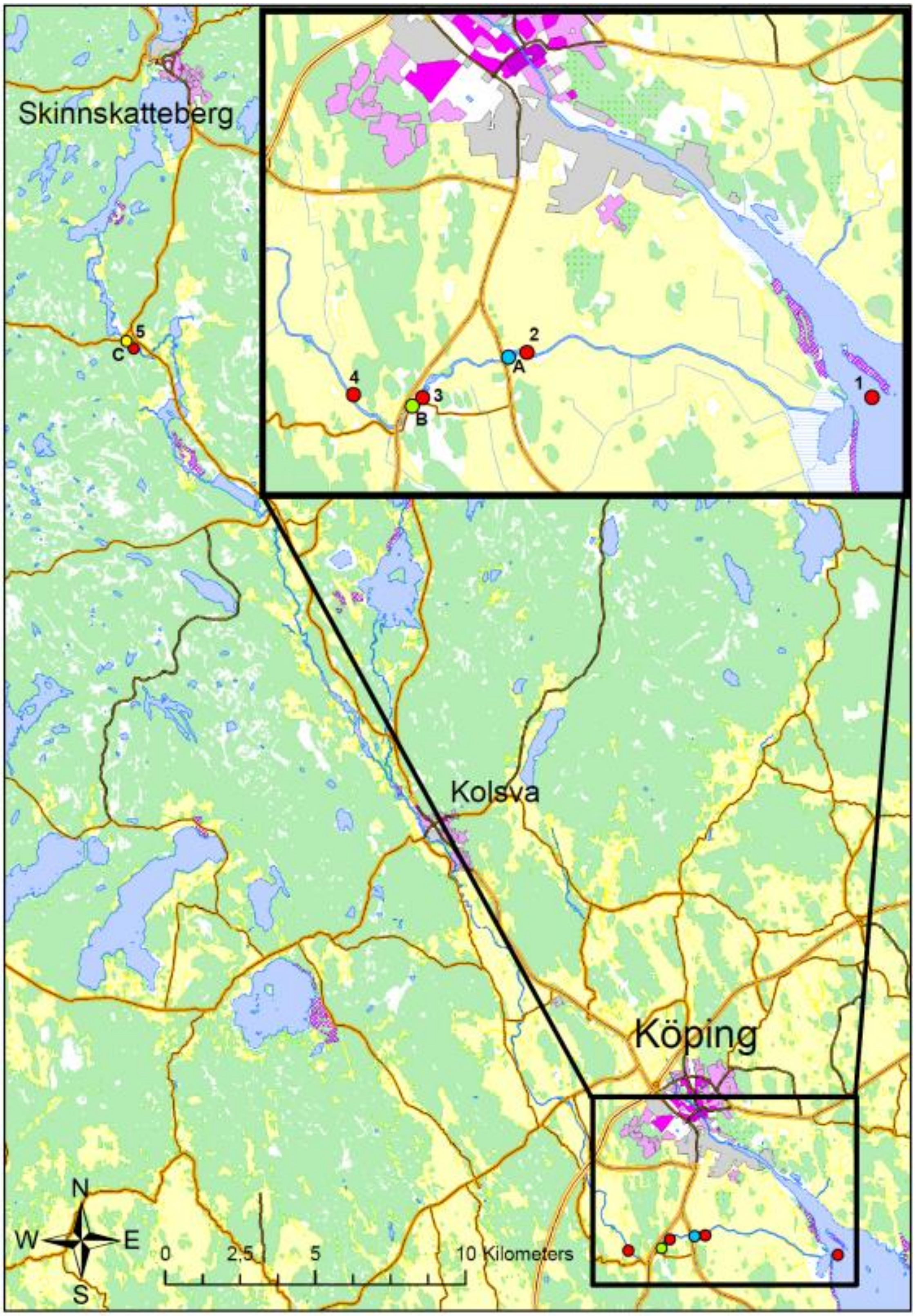
8. Appendix



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