Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

**Faculty of Natural Resources and Agricultural Sciences**

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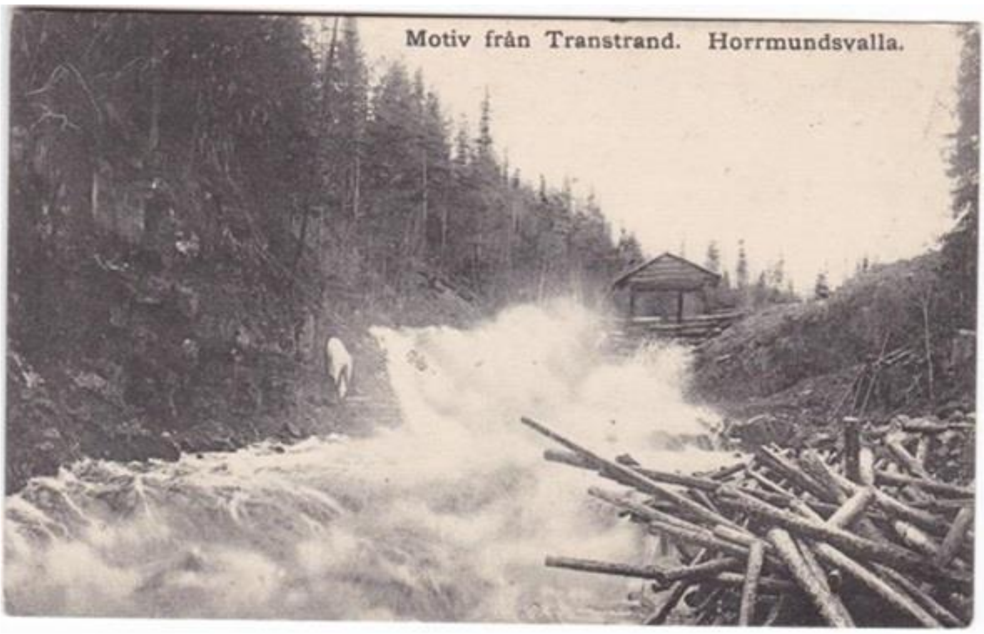
## Methods to assess historic passability. Case studies of migration barriers

## Naturliga vandringshinder för fiskar innan kraftverksutbyggnaden

*Anders Johansson*



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# Abstract

Is it necessary to build fishways at all artificial migration barriers to restore and sustain biodiversity? Hydropower plants have often been built at places where a difference in height has been used to gain more power, leading to the hypothesis that many hydropower dams have been built at natural migration barriers. How are Swedish running waters (not large rivers) assessed with respect to historical passability for fish at natural migration barriers and dams? How does one study a specific location with respect to the historical passability for different fish species?

The methodologies that are evaluated in this thesis are relevant and specific information from a habitat mapping from Värmland County, where 2 903 km waterways already have been surveyed. The evaluation in this thesis has been made on various types of artificial migration barriers, to find out whether natural migration barriers have been replaced by artificial migration barriers. A detailed study was made on a hydropower plant in a tributary to the Västerdalälven River, Horrmundsvalla. Several different methods were used to investigate the historical passability for different fish species. The methods consisted mainly of historical information and DNA analysis of brown trout (*Salmo trutta L.*) upstream and downstream of the waterfall, Horrmundsvallafallet.

Field surveys of Swedish waters are often done with the use of “habitat mapping” (or Jönköpingsmodellen). My conclusion after evaluating this habitat mapping, is that the current mapping methodology gives an unclear result with respect to historical passability for different fish species. The most likely reason to this unclarity is the design of the protocol template used in the habitat mapping. In the protocol template, one can choose whether it is a natural or artificial barrier to migration. There is however, no question in the template that can be used to indicate the historical passability for different fish species. I therefore propose to change the protocol template, with the aim that historical passability for different fish species also can be commented.

Historical information indicates that brown trout have not been able to pass Horrmundsvallafallet, though some sources refer that eels (*Anguilla Anguilla*) have been able to pass. However, this must be very unlikely when one reflects the biological conditions and life cycle of eels. Bream (*Abramis brama*) are the fish species that dominate the lake upstream Horrmundsvallafallet. However, it is not likely that bream have been able to colonize Lake Horrmunden through Horrmundsvallen on their own, given the breams physiological capacity and watercourse morphology.

The DNA analysis of trout populations upstream and downstream of Horrmundsvallafallet showed that the difference in the $F_{ST}$ (genetic difference between the two populations) was 0.023. The difference in $F_{ST}$ could be interpreted as that both populations initially (prior to

1960 when the hydropower plant was built) belonged to the same population, but after that have been isolated. The explanation for why the $F_{ST}$ value was so low could however be due to the stocking history of trout in the lake upstream of the two populations. If one should conduct an investigation of historical passability based on DNA analysis it is important to check and examine the historical stocking or transfers of fish in the water systems of interest.

In summary, I conclude that Horrmundsvallafallet was a total natural migration barrier to all existing fish species prior to human impact of the watercourse. Historical information is important for assessing historical passability for fish species. However, one should be careful and judge the credibility or plausibility degree of historical sources that are used. The habitat mapping done by the County Administration Board of Värmland indicates that natural migration barriers occur at hydropower dams. The share is difficult to determine today given that Habitat Mapping methodology does not reflect historical passability. Despite the shortcomings of the methodology, over 5 % of hydropower dams could have been built by a historically definitive natural migration barrier for trout.

# 1 Table of Contents

# 2 Foreword

This report is a Master's Thesis (30 credits) in Biology at the Swedish University of Agricultural Sciences (Sveriges Lantbruksuniversitet, SLU), Department of Aquatic Resources. I had three supervisors who all have advanced knowledge of fish migration, migration barriers and hydropower during this thesis work: Johan Östergren, SLU, researcher focused on diadromous fish species; Marco Blixt, fish manager at Fortum Sverige AB; Dag Cederborg, consultant at SWECO Environment AB with a focus on water environmental issues. This report is addressed to people working for authorities e.g. county administration boards, water authorities etc., those who work with these issues in the hydropower industry, researchers and students who wish to pick up where this report ends and wants to answer the supplementary questions, as well as an interested public who want more information about the migration of fish species.

The focus of the thesis was originally "natural migration barriers at hydropower dams," but has during the run of the work also included scrutiny of how inventory of migration barriers are today, based on the habitat mapping (Jönköpingsmodellen).

# 3 Dictionary

"Obstructions are many and varied. It would be useless to attempt to classify them beyond distinguishing between the comparatively mild, the definitely difficult, and the completely impossible."- Pryce-Tannatt (1938).

**Migration barrier**: A dispersal barrier that exist within a catchment area. Can be artificial or natural. Can be partial, definitive or total.

**Total migration barrier**: A migration barrier that most likely prevent dispersal or migration for all fish species in the system.

**Definitive migration barrier**: A migration barrier that most likely prevent dispersal or migration of one specific fish species.

**Partial migration barrier**: A migration barrier that most likely prevent some fish individuals within a species to pass the barrier.

**Passable migration barrier**: A migration barrier that most likely does not prevent dispersal or migration for a majority of fish individuals within a species.

**Temporal migration barrier**: A migration barrier that most likely prevent migration some of the time, usually at low flows and at disadvantageous temperature conditions.

**Passability**: Often refers to how big proportion of the measured individuals within a species that can pass a barrier, ranging from 0 to 100 %.

**Natural migration barrier**: A migration barrier that is not made by humans; rapid, waterfall, beaver dam etc.

**Artificial migration barrier**: A migration barrier that is made by humans; dam, culvert, wire etc.

**Connectivity in streams**: "The ability to disperse and free passages for animals, plants, sediments and organic material in upstream and downstream directions, and from the river to the surrounding land areas, in relation to the reference condition" (HaV, 2013).

**Status classification connectivity**: "In upstream and downstream directions, should be assessed on fish species with migration needs that occur in the water surface, according to the reference condition" (HaV, 2013).

# 4 Introduction

Is it necessary to build fishways at all artificial migration barriers to restore and sustain biodiversity? One of the most common artificial migration barriers to fish in Swedish rivers and streams are dams. There are approximately 11000 of them in Sweden. When the expansion of hydropower plants intensified in the 1940s and 1950s, the authorities, power plant owners and expertise in the area assumed that the damage to fish and other aquatic fauna, as a result of the expansion, could be solved through various forms of compensation measures (fish ladders, trap- and transportation, narrow trash racks, fish stocking, restocking animal nutrition (*Mysis relicta*), etc.). Among other things, Alm (1927) claimed that “any destroyer; power plants, industry, log driving and others", would compensate the loss of fishing in the waters "by fish farming in one way or another”. Focus of the compensatory measures was primarily to the loss of fish catches of mainly salmon and other highly migratory species as a result of hydropower dams. Hydropower plants have often been built at places where a difference in fall height have been used to gain electricity, leading to the hypothesis that many hydropower dams have been built by natural migration barriers. One can also imagine that the expansion of hydropower dams occurred at falls and rapids that were partial migration barriers to fish migration.

Biogeographical barriers (dispersal barriers) determine which species that can colonize a local habitat (Rahel, 2007). Biogeographical barriers in freshwater systems can be visualized in three spatial levels: continental, interbasin and within basin. The largest spatial scale, continental; freshwater fauna are isolated by oceans, mountain ranges and deserts. The next biogeographical barriers are between major river basins; these areas are isolated from fish species that are unable to spread through salt water or drainage basin watershed. Within the catchment; waterfalls and rapids function as biogeographical barriers to freshwater organisms. Waterfalls and rapids are named natural migration barriers in this study. Historically biogeographical barriers have been one of the main factors that determine which fish fauna that can be found in an ecosystem (Rahel, 2007).

Swimming speed and jumping ability are the two main parameters that determine which fish species that can pass a natural migration barrier and colonize a habitat upstream. All fish species have different “styles” of swimming (Videler & Wardle, 1991). How fast a fish can swim and for how long depends on many factors. Videler and Wardle (1991) showed how cod (*Gadus morruha*) length and the water temperature affect their swimming speed. Those two factors are probably the most important, regardless of fish species. Fish are usually said to have three different swimming speeds (Calles et al. 2013). The first is “sustained speed”, the fish will be able to maintain the same speed for at least 200 minutes. The second speed is "prolonged speed" and can be held between 200 minutes and 15-20 seconds. The fastest speed is called “burst speed”, it can be held at maximum 15-20 seconds. Burst speed is primarily used for predation or avoid being predated on, but can also be used for passage of some migration barriers. When passing a difficult obstacles, the burst speed will result in an increase of lactic acid production in the muscles and also in a long recovery time (Calles et al. 2013). The same goes with a fish specie's ability to jump. Some fish species such as trout and salmon are shaped to be able to jump high. These have been documented to be able to jump between 1 and 2 m, in extreme cases up to 3,7 m (Calles et al. 2013). Other species, such as bream, have a more limited jumping ability (Calles et al. 2013).

Human activity has created many ways for freshwater fauna to spread between different biogeographical barriers (Rahel, 2007). Between continental barriers, many fish species have been restocked, and these releases are often well documented. The first Asian fish species (carp, *Cyprinus carpio*) came to Sweden in 1560 and two North American fish species (brook trout (*Salvelinus fontinalis*) and rainbow trout (*Oncorhynchus mykiss*)) were introduced to Sweden in 1892 (Pakkasmaa & Petersson, 2005). However, it has been more common that fish species have been moved between and within river basins in Sweden. In Sweden, native fish species have been restocked since the Viking age. It is estimated that every third lake in Sweden over four hectares have at least one introduced fish species (Schindler et al. 2001). According to Alm (1920) fish have been restocked in over 800 lakes in Sweden between 1850 and 1916. Between 1917 and 1935 over 2800 fish restocking events have been recorded in Sweden (Brundin, 1939). Whitefish is probably the fish species that have formed most new populations in the country (Pakkasmaa & Petersson, 2005). An alien species is a species that did not originally appear in the country but was moved there after 1800. However, also native species should be considered as alien species if they have been moved into areas they have not been able to establish themselves in a natural way (Pakkasmaa & Petersson, 2005).

Between and within river basins, channels have enabled fish species to spread to new habitats (Rahel, 2007). In the United States, the Chicago Sanitary and Shipping Canal was opened in 1900. The canal allowed fish to pass from one basin to another which enabled several species to pass between catchment areas (Rahel, 2007). In Sweden, e.g. Göta canal is the equivalent to the Chicago Sanitary and Shipping Canal, which makes such a passage between basins possible. In 1829 the Welland Canal was built and allowed fish species to pass the 49 m high Niagara Falls (Rahel, 2007). Sweden's equivalent would be the Trollhättan canal (1800) that enabled increased dispersion of freshwater organisms over Trollhättefallen (Degerman et al. 2001).

There are many effects of fish species and freshwater organisms that are introduced to new freshwater systems (Pakkasmaa & Petersson, 2005). Even stocking of fish species that already exist in a freshwater system can have adverse ecological effects

(Pakkasmaa & Petersson, 2005). The effects can vary from predation, competition for food to genetic effects on fish populations (Pakkasmaa & Petersson, 2005). The above example of Göta canal now allows the invasive species zebra mussel to spread throughout the canal system (Smith & Lundberg, 2013). The example of Trollhättefallen enabled the increased spread of eels upstream in the system, which eliminated or greatly reduced the crayfish in and upstream Lake Vänern (Pakkasmaa & Petersson, 2005). However, introduced species do not always need to have a great effect on the ecosystem. If the introduced species disappear almost immediately after the introduction, the impact on the ecosystem often is moderate and transient.

Recolonization of historical habitats through restoration of migration routes is most often seen as positive for biodiversity. In Sweden, most artificial migration barriers have proposed actions linked to increased connectivity i.e. building fish ladders or bypass channels. Today there are 7499 pieces of actions linked to connectivity improvement, fish way or removal of migration barriers (VISS, 2015; VISS, Water Information Systems in Sweden, and both suggested and already completed actions are included). Of these actions about 1200 have already been completed (VISS, 2015). Of the around 2100 hydropower stations in Sweden, about 10 % have some form of passage (Kling, 2015).

One interesting question then is: which methods have been used to determine the target species in the systems? In other words; which fish species have occurred naturally in the system, which fish species have been able to pass a historic natural migration barrier and how many passed the location before human influence (Calles et al. 2013).

Today there are only a few public reports which investigate the historical passability for fish by artificial migratory barriers in waterways. One of them is Andersson (2005) in which he investigated if it was historically possible for salmon to pass the rapids at Hedefors in Säveån. Andersson used historical maps and images to get an idea of how the location appeared prior to the dam. In addition, testimonies of various people was also used to determine whether salmon had occurred upstream of the Hedefors rapids or not. The result of the testimonies can be interpreted that there had never been salmon upstream of the rapid or that salmon actually passed the rapid. Hedefors has since, been investigated by genetic methods, if trout has been able to pass the rapids (Dannewitz et al. 2012). In both cases of salmon and trout, there have been different preconditions to assess historic passability for these species. In general there is very little available literature on how to investigate historical passability (based Google Scholar search for keywords: “historical passability”, “natural migration barriers” etc.).

However, there are several different methods one can use to assess the current passability for fish species for barriers that are not influenced by humans. M. Schröder

(2016) used telemetry on brown trout to investigate how many individuals that passed a steep waterfall in Norway. Power & Orsborn (1985) used hydrological methods to simulate water velocity at waterfalls and compared the speed of the water against various fish species swimming and jumping ability. Spens et al. (2007) used geographic information system (GIS) to predict pike populations in lakes in Northern Sweden. Spens predicted pike populations at 95.4 % of the lakes based on the slope of the watercourse. Meixler et al. (2009) used a passability model for dams and waterfalls for migratory fish species in the United States. Meixler et al. (2009) simulated swimming speed, jumping ability and depth immediately downstream of dams and waterfalls to investigate if the physical parameters corresponded to what the different fish species are able to pass. All of the above methods can be difficult to apply to examine historical passability by artificial migration barriers for different fish species. The above methods are generally directed at assessing current passability, not passability prior to human impact.

Molecular technology (e.g. DNA genetic markers) can be used to investigate the genetic differences between two populations of fish and thereby can be an important tool to determine if there has been a natural migration barrier in one place prior to human impact. Heterozygosity ($H_e$) and allelic richness ($A_R$) are two measures used to describe the genetic diversity within a population. To describe the genetic differences between two populations $F_{ST}$ are often used. $F_{ST}$ is largely based on $H_e$ between two populations. Deiner et al. (2007) found that there was a genetic difference in rainbow trout between natural migration barriers and artificial migration barriers in the Russian River in the United States. There was less genetic diversity for populations that were isolated by waterfalls than by dams. Populations that were above dams were more genetically similar to all populations that were below all kinds of barriers. Both natural and artificial migration barriers affect the dispersal possibilities different for different fish species (Deiner et al. 2007). Isolation time differ between natural and artificial migration barriers. This makes it possible to investigate whether or not a dam has been a natural migration barrier to one fish species with DNA analysis. How much of the genetic material that has disappeared from the population by genetic drift, depends on the size of the effective population ($N_e$), given that the population is isolated. The effective population size is the number of individuals in a population that actually contributes with genetic material per generation. Because many of the old rapids and falls in Swedish rivers are or have been exploited, it is often impossible to visually determine whether there has been a natural migration barrier in one place prior to the dam or not. Genetic methods could be a good way to determine which fish species that historically have been able to pass e.g. a hydropower dam without knowing the morphology of the historical rapids or fall.

Historical documentation belongs to the more "traditional methods", which are mostly used in the investigation of historical passability for fish (Andersson, 2005). The documentation consists mostly of water rights verdicts, old maps, historical photos and interviews. In addition, historical documentation of log driving, mills and sawmills in the area, could help to assess which fish species that were able to pass a site. Reviewing historical documentation is important to get an understanding of the human impacts on the current site, in order to get an view of the site at given times and whether the conditions for different fish species ever have been suitable for upstream migration. It is also important to know whether human activity has impaired or improved dispersal opportunities for freshwater organisms at the site. Historical pictures often weigh heavily in assessment of historical passability. Picture show what it looked like at the site at the time the picture was taken and one can usually say something about the passability of different fish species at the time.

Below, two new investigative methods are presented. Their purpose is to help to determine historical passability for different fish species, their individual capabilities will be discussed in chapter 6 and 7.

I. Biogeographical dispersal barriers have affected what fish species that can colonize a habitat. Spens (2007) found that the names of lakes in northern Sweden could be traced to trout populations. Names of a place often extend further back in time than what can be found in archives about the location. The prime question to be asked in this kind of investigation is; are there any places, lake or rivers name that derived from various fish species that have been able to pass a natural migration barrier at one time?
II. The second method is also based on historical names, not fish species names but that of the actual migration barrier. So called nature names were used to quick and easy refer to a certain place (Pamp, 1988). Names of flowing water stretches have shown to generally include; *current* (-ström), *rapids* (-fors), *falls* (-fall) and *cliff* (-stup). Can the name of the migration barrier say something about the passability of different fish species in the same way as names of lakes can be traced to various fish species?

Water authorities and county administration boards have a great responsibility in water management. The authorities ensure that the Water Framework Directive (WFD, 2000/60 / EC) is followed. The goal with the WFD is to ensure that all surface water bodies achieved good ecological status/potential by December 22, 2015. Surface water bodies that did not reach the objectives have in most cases been provided exceptions to 2021, or in some cases to 2027 (Naturvårdsverket, 2007).

Surface water bodies can be classified to any of:

- High status / maximum potential

- Good status / potential
- Moderate status / potential
- Unsatisfactory status / potential
- Poor status / potential.

Biological factors are the primary determinants whether the water body can reach good or high status/potential (EPA, 2007). However, it would be unreasonable to investigate all water bodies in a county and to which biological class they correspond to. Therefore expert assessments are made. To describe the physical impact on the watercourse, an assessment criterion for the hydromorphological pressure is used. There are three parameters to be determined in order to classify continuity (current connectivity). They are the occurrence of artificial migration barriers, fragmentation degree and barrier effects. All these parameters can be determined based on habitat mapping (Naturvårdsverket, 2007). All three parameters are based on the artificial migration barriers. Recently, a fourth quality factor, connectivity, has been introduced to replace continuity. This quality criterion is simply based on how many fish species that are missing in a surface water body due to artificial migration barriers.

Then the relevance of habitat mappings, in terms of describing the physical impact on a watercourse, comes into question. The new quality criteria, that aims to describe the lack of a fish species due to artificial migration barriers, matters less when the ecological dilemma remains. It is usually a dam that blocks fish migration.

Given the lack of knowledge to assess historical passability at artificial migration barriers, it is important to consider which methods could be useful in future assessments. In line with what has been said earlier in the introduction, miscalculation of historic passability by artificial migration barriers can have negative ecological consequences.

This report suggests tools to investigate the historical passability for fish species by artificial migration barriers.

## 4.1 Aim

The purpose of this study is to investigate if there have previously been natural migration barriers at dams and hydropower dams, either definitive or partial. This knowledge is important in order to avoid building fauna passages or fish ladders where there has been a natural migration barrier in the reference condition. Further, to investigate whether existing inventory methods are satisfactory or not for capturing former natural migration barriers at today's artificial migration barriers. The inventory (habitat mapping) of migration barriers made by the County Administrative Board of Värmland is reviewed. This study will also in detail compare different methods that one can use when assessing natural migration barriers by existing dams and hydropower dams. What are the pros and cons of the different methods?

### 4.2 Goals

(I) Investigate the proportion of hydropower dams that originally may have been built at natural migration barriers and examine whether the existing method (habitat mapping) is adequate with a focus on dams.

(II) Study in detail and compare a few different methods at one of Fortum's hydropower dams (Horrmundsvalla).

## 5 Methods

### 5.1 Habitat mapping

Data has been provided from County Administrative Board of Värmland of the survey of migration barriers, whit a methodology based on Halldén et al. (2002). The data has been processed in Excel 2010 and the statistical program R for analysis. This was done to find correlations between different parameters and to evaluate if this method is adequate for finding historical natural migration barriers by dams.

### 5.2 Toponymy of water stretches

Name of fast flowing water stretches have shown to generally include the following after subsequent name; *current* (-ström), *rapids* (-fors), *falls* (-fall) and *cliffs* (-stup). In order to confirm or dismiss that names of natural migration barriers can say something about the passability of various fish species, data was collected from “List of Swedish waterfalls” and compiled regarding distances and heights at various sites with guiding names. Names of water stretches have only been taken from the larger rivers. A selection of fall heights and distances have been extracted from the historical data in "List of Swedish waterfalls" 1913-1942 (several editions) by “Kungliga vattenfallsstyrelsen och statens meteorologisk-hydrografiska anstalt”. The data from this source can be regarded as slightly inaccurate as the mapping include long distances.

## 5.3 *Case study Horrmundsvalla*

### 5.3.1 Study area

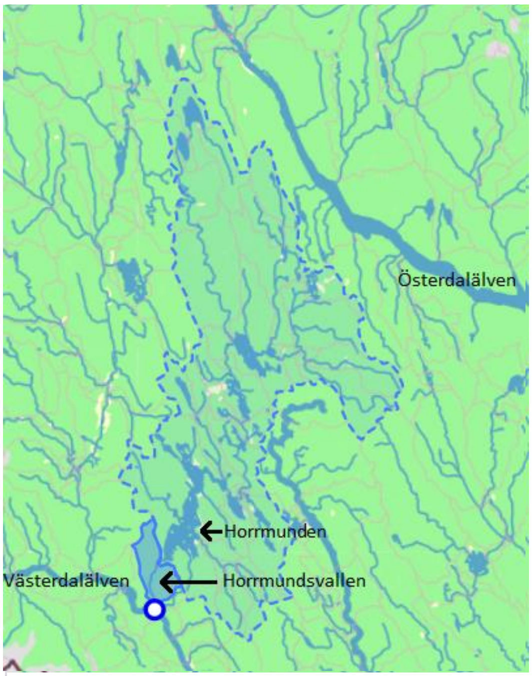


Figure 1: Lake Horrmunden catchment area, dotted line. Horrmundsvallen local catchment area, soild line (SMHI vattenwebb, 2015).

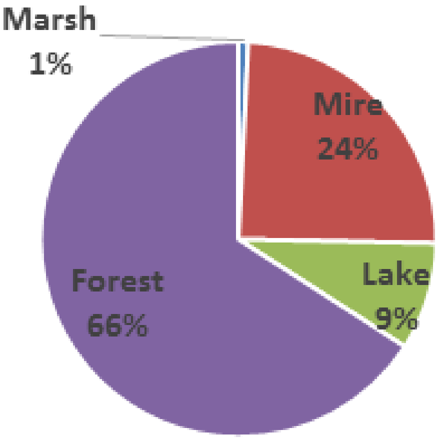


Figure 2: Land use in the whole catchment area.

Horrmundsvallen watercourse is located in Malung-Sälen municipality in Dalarna (Figure 1). The river flows into Västerdalälven River and has its original water flow from the Lake Horrmunden. Today there is a hydropower dam that stops the water flowing into Horrmundsvallen. The water goes instead through Horrmundsvalla power station (built in 1960) and passes through a tailrace tunnel directly into Västerdalälven River. The power station has an annual production of 25 GWh and an water capacity of 11 m$^3$/s. Horrmunden has a catchment area of 354 km$^2$ and a MQ of 4 m$^3$/s (SMHI vattenweb, 2015). The land use in the catchment area consists mostly of forest and mire, a total of 90 % (SMHI vatenweb, 2015) (Figure 2). Horrmundsvallen watercourse has a local catchment area of 10 km$^2$. The river is 3.7 kilometers long, with a total vertical drop of 90 m and an average water flow at the mouth to the Västerdalälven River of 0.43 m$^3$/s (local runoff) (SMHI water Webb, 2015). Furthermore, Lake Horrmunden is a storage reservoir with a regulated amplitude of about 2 m. Horrmundsvallen have poor ecological status, mainly because it is a “dry” streambed. An assessment of the ecological status for the watercourse, done in 2009, found it to be in unsatisfying status (VISS, 2015). The biological parameter that was investigated was fish fauna. However, at the same time the fish community parameter was assessed to have good ecological status. The fish community showed a relatively high density of trout (30 ind./100 m$^2$) and a few bullheads were found during the electrofishing in 2006-08-29 (Sers, 2016). In 2015 a new assessment of the ecological status was made by the water authorities. In this assessment, the river received poor ecological status. In the later assessment the investigated parameters were changed from quantities of fish to expert opinion. The proposed action to achieve good ecological status is a fish ladder or bypass channels to create connectivity between Västerdalälven River and Lake Horrmunden.

### 5.3.2 Names in the catchment area

All names that were water surfaces and land surfaces in close to water bodies were collected using a digital map. Which place, lake or river name can be attributed to various fish species or fishing methods in the river basin? Is it possible to apply Spens (2007) method of fish names in the catchment area to investigate what fish species that have been able to pass a natural migration barrier?

### 5.3.3 DNA of brown trout

Tissue samples (fin clips) were taken from brown trout in Horrmundsvallen during electrofishing, 1 Oct. 2015. This was done to examine whether trout upstream and downstream of Horrmundsvallafallet (front picture) originally formed the same population from before 1870 or not. In total 25 tissue samples were collected downstream and 32 upstream of Horrmundsvallafallet. Tissue samples were from five different locations (sites) in the watercourse (Figure 3). Due to a low amount of tissue samples collected from trout, samples from all age groups were considered. The tissue samples were stored in alcohol prior to analysis. Microsatellites were used to determine the genotype and a total of ten microsatellites have been studied. Microsatellites analyzes are described in Dannewitz et al. (2012).

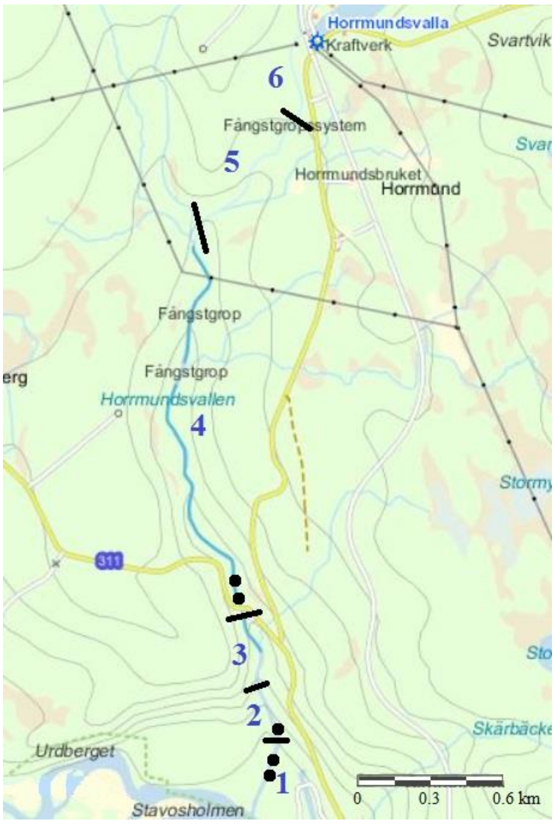


**Figure 3: Electrofishing sites and habitats for trout. Dots shows electrofishing sites and where tissue samples were taken. Stretch 3 is the suspected definitive natural migration barrier for trout. Stretch 3, 5, and 6 have been classified as zero habitat for trout.**

#### 5.3.3.1 Statistical analysis of DNA results

A series of statistical analyzes have been made to provide estimates of population structure, size and genetic diversity. The statistical analysis was done by J. Östergren. The interpretation of the results has been made by the author.

COLONY 2.0.6.1 (Wang & Jones, 2009) was used to estimate the number of full- and half-siblings in the two populations. This was done to determine if the samples from Horrmundsvallen gave an unrepresentative picture of the populations (many individuals from the same family group). If an unrepresentative picture of the trout population would appear, the subsequent analyzes may be incorrect (Hansen et al. 1997).

GENCLASS2 (Piry et al. 2004) was used to examine what population an individual most likely belongs to. This was done to determine if some individuals from the downstream population were more likely to belong to the upstream population or vice versa. Also analysis if individuals who are more likely not belonging to neither of the two populations.

STRUCTURE (Pritchard et al. 2000) was used to obtain information about how populations are related to each other. STRUCTURE identifies a material of unknown origin and divides them into how many "populations" most likely there are within the material, also known as "genetic clusters" (K). The program uses Hardy-Weinberg equilibrium and identifies a number of clusters that have the least deviations from Hardy-Weinberg equilibrium.

FSTAT (Goudet, 1995) was used to calculate $H_e$ (expected heterozygosity), $A_R$ (allelic richness), $F_{IS}$ (average deviation from Hardy-Weinberg equilibrium), $F_{ST}$ (genetic difference between two populations) and $G_{ST}$ (genetic difference between two populations alternatively index to $F_{ST}$).

PHYLIP (Felsenstein, 2004) was used to examine how the trout in Horrmundsvallen relates to other trout populations in Sweden and Dalälven River. The program uses "neighbour-joining" method of chord distances (DCE).

#### 5.3.3.2 Calculations of the effective population size and loss of genetic material

Calculations were made on $H_e$ and $G_{ST}$ to investigate whether or not the two populations belonged to the same population in 1870 (the same calculation made in Dannewitz et al. (2012)). The year 1870 was chosen because that year a weir was built over Horrmundsvallafallet which most likely made it impossible for trout to pass upstream of the fall.

Effective population size ($N_e$) is a measure of how many individuals actually contributes with genetic material per generation. It is strongly linked to the rate of loss of genetic material over a period of time. The relationship between reduced genetic diversity (h) and $N_e$ per generation is usually written as $h = 1-(1/2\ N_e)$ (Allendorf et al. 2013). Because trout upstream Horrmundsvallafallet have had limited space since 1870, I calculated how big the upstream trout population must have been for the loss of genetic diversity to be reasonable, given that it is isolated. For calculating the loss of genetic material ($H_e$ and $G_{ST}$) the Hendry et al. (2000) calculation formula is used. In total, there have been four assumptions: (I) a generation time of 4.6 years (Dannewitz et al. 2012), (II) downstream population has no loss of $H_e$ (due to less degree of isolation because it is in contact with populations in Västerdalälven River), (III), both populations originally had the same $H_e$ at the time of isolation and (IV) that no trout were able to migrate uppstream the waterfall Horrmundsvallafallet since 1870.

A simple population estimate ($N$) was made on trout upstream of Horrmundsvallafallet based on the electrofishing data. This was done to investigate if it is reasonable that the loss of genetic material, or the genetic difference between the populations, has occurred since 1870. The population estimate was made solely on the stretch (length) that was considered appropriate habitat for trout and not per area. Trout density was also assumed to be reduced upstream in the river because due to lower water and habitat quality (log driving had affected the stretch). Trout density assumed to decline 5 %, 10 % or 15 % per 100 m from the largest population by the fall. Stretch 5 and 6 were classified as a zero habitat for trout (Figure 3). Stretch 4 was the only stretch upstream of the fall that was considered appropriate habitat for trout. The effective population size ($N_e$) is assumed to vary between 10 % and 20 % of the total population ($N$) based on several studies of *Ne:N* conditions on trout populations (Palm et al. 2003; Charlier et al. 2011; Allendorf et al. 2013). For this study 10 % and 20 % have been chosen to produce an interval of the effective population size that occurs in Horrmundsvallen. It is difficult to calculate the exact *Ne:N* ratio required for a population, however for this study the 10 % and 20 % ratio is sufficient.

#### 5.3.3.3 DNA comparison

What are the expected differences in $F_{ST}$, $H_e$ and $A_R$ for populations that are separated by barriers? A comparative study has been made of natural and artificial migration barriers with the results from Horrmundsvallen in this study and other studies were microsatellites have been used. Data has been obtained from studies made on the Salmonidae family (appendix 1).

### 5.3.4 Traditional methods

Traditional methods include the collection of historical information which may be relevant for assessing the passability of various fish species. In this list historical documents are presented which are relevant to assess historic passability:

- All water right permits and the basis of all water right permits for Horrmundsvalla power station(1939-1971).

- Log driving documentation from 1883 relating to a floating inspection of the catchment area and the floating conditions in the catchment area (1873-1936).
- Historical pictures from SMHI historical archives (SMHI, historical gallery, 2015).
- An 8-mm film about the log driving in Horrmundsvallen by Mats Elfqvist (1960).
- Historical maps from the land survey (Lantmäteriet).
- Interview with Sune Brändholm (chairman of Malung-Sälen fishing association) regarding the fishing conditions in the catchment area.
- Historical information from the “Kungl. Maj:ts Befallningshafvandes femårsberättelser, Kopparbergs Län.” an old document about the county of Dalarna (Statistiska centralbyrån , 2015).
- Historical information and maps from the National Heritage Board (RAÄ).
- Information from the ”Förteckning över Sveriges vattenfall” (List of Swedish waterfalls) published by “Kungliga vattenfallsstyrelsen och statens meteorologisk-hydrografiska anstalt”.

### 5.3.5 Field visit to Horrmundsvalla

During the field visit to the watercourse and the migration barrier, information about the habitat quality for trout and information on Horrmundsvallafallet was collected. Migration barrier morphology, such as height, distance and slope were noted during the field visits. Entering possibility (pool conditions) for fish was estimated as well.

# 6 Results

## 6.1 Habitat mapping

*What kinds of different migration barriers and how many are there, in Värmland? What types of dams are natural migration barriers? A study of natural migration barriers based on raw data from Värmlands habitat mapping.*

The habitat mapping of Värmland county is probably the most comprehensive survey of aquatic environments in Sweden. The survey started in 2005 and lasted until 2010, with a total of 2903 km waterways inventoried. The purpose of the survey was to get an overall picture of the watercourses and the environment around them as well as describe human impact on the waters. The results of the survey were meant to provide a basis for restoration work, protection of environment and status classification of hydromorphological quality elements. One of the many milestones of the project was to describe migration barriers and examine the fragmentation degree of the watercourses (County Administrative Board of Värmland, 2013). The methodology for the habitat mapping is primarily directed to waterways in smaller rivers.

The methodology used to survey migration barriers is partly based on Abrahamsson’s (1995) "methodology for surveying rapids and falls", in which he investigated different methods used to identify rapids and falls. A total of 41 items were assessed as rapids after field visits. The sources he used included maps, aerial photographs, dam lists, electrofishing protocols, benthic fauna protocols and stream inventories. Aerial photos could identify 71 % of the rapids and was rated as the best identification method. Later, the methodology has been developed and revised by Halldén et al. (2002) in "Habitat mapping - streams". The methodology proposed by Halldén et al. is a method that is broadly used to survey migration barriers in Värmland.

The basic information gathered in the field are; type of obstacles, drop height, flow, dam chest appearance, number of spillways or drums, dry furrow and if it is a natural migration barrier (Table 1). Also to be noted is function or the use of dams today and the function it had in the past. An assessment is made whether the barriers are passable, partial or definitive migration barrier for roach and trout separately. And finally suggested actions that should be done at the barrier.

Table 1. Basic information that should be collected about the migration barrier.

| **Migration barrier information** | **Information about respective parameter** |
|---|---|
| **Type of obstacle** | Rapid/fall, beaver dam, debris, other natural object, dam, culvert, blast rock or other artificial object |
| **Total head** | Head height: The whole drop height of the barrier, and if there are several drops the total height should be listed. |
| | Used head height: The height that is used by a hydropower plant |
| **Flow** | Assess: The flow at the site in $m^3/s$ |
| | Water flow: Asses if there is a low (L), middle (M) or high (H) water flow. |
| **Dam chest** | Length and width of the dam chest as well as a drawing of the dam. |
| **No. of Spillways/Culverts** | Number of spillways by the dam or number of culverts by road passage. |
| **Dry streambed** | If there is a dry streambed and how long it is. |
| **Natural barrier** | Assess if the migration barrier has been a natural migration barrier. Since it is difficult to determine one can chose; Yes, No or Unclear. |
| **Culvert information** | Information about the culvert´s length, diameter, water velocity and so on. |

### 6.1.1 Result Habitat Mapping in Värmland

Of the 2385 migration barriers that were surveyed in Värmland, there were most rapids / falls (661 pcs) followed by dams (624 pcs) and finally beaver dams (469 pcs) (Figure 4). Blast rock (161 pcs), culverts (150 pcs), "other artificial objects" (130 pcs) and debris (136 pcs), constituted a smaller part of the migration barriers in the landscape. The fewest migration barriers were made out of "other natural objects", in total 54 pieces. The total distance surveyed was 2903 km long, divided into 478 water bodies. Of the 478 water bodies there were 57 water bodies that completely lacked migration barriers for trout. Migration barriers that are considered natural are rapids / falls, beaver dams, debris and "other natural objects." The artificial migration barriers are dams, culverts, "other artificial objects" and blasted rock. Of the total 2385 migration barriers surveyed, 1319 of these were natural migration barriers and 1066 as artificial migration barriers in a rough estimate.

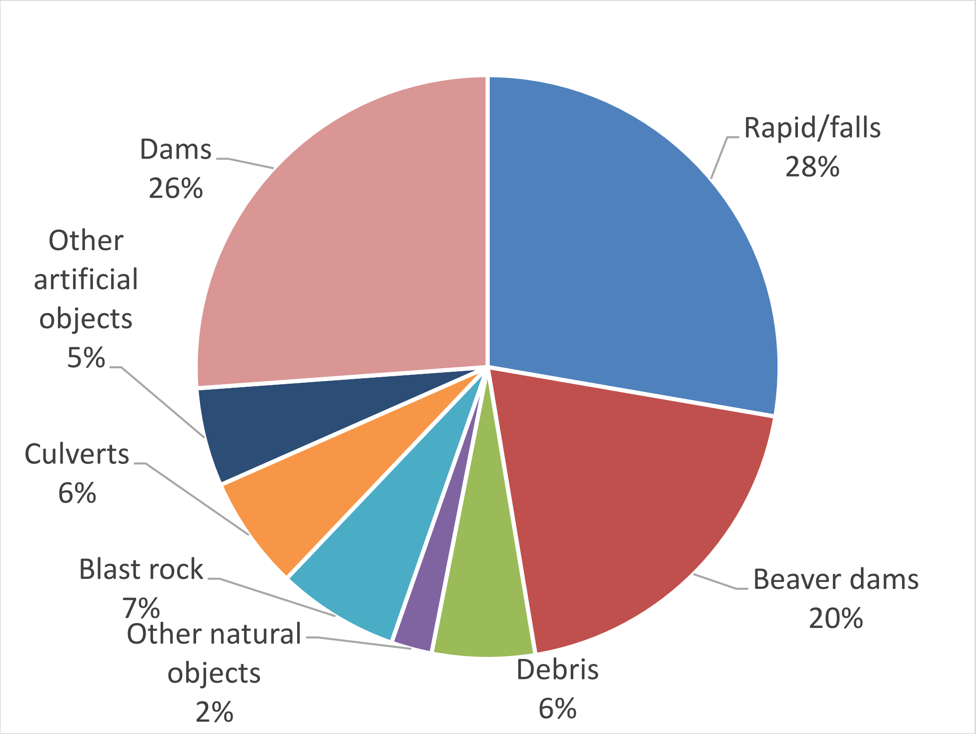


Figure 4: Different types of migration barriers in Värmland. Total 2385 pieces inventoried.

Contemporary use of dams in Värmland was divided into hydropower dams, regulating dams, other dams and those not used (Figure 5). Most dams surveyed seen to have no function or use today, 270 pieces. Furthermore, there were 190 pieces of regulating dams and 130 pieces of hydropower dams. There were 18 dams that had another function than the dams above and 12 dams who had not been classified regarding present usage. Fourteen of the hydropower dams were classified as natural migration barriers (Figure 6). Regulating dams had 9 classified as natural migration barriers. Of the dams that had no contemporary use (270), 46 were classified as natural migration barriers.

Of the Culverts only four were classified as natural migration barriers. The migration barriers that were in the category blasted rock, 117 of 161 were classified as natural migration barriers. Migration barriers which were of the type "other artificial objects" 14 out of 130 were classified as natural migration barriers.

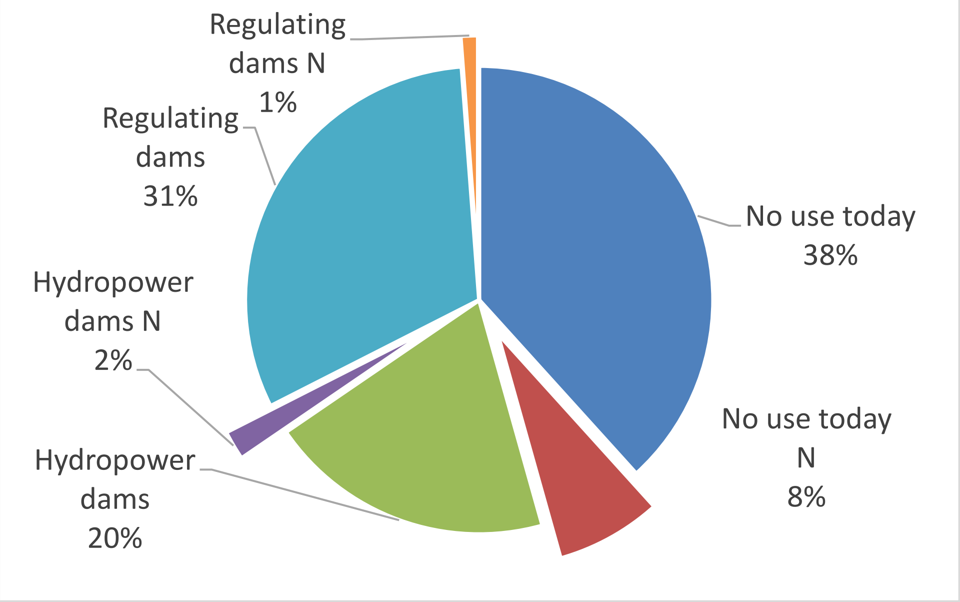


**Figure 6: Proportions of dams that have been classified as natural migration barrier (N in the diagram) for hydropower dams, regulating dams and dams that have no use today. Total of 594 dams, “different use” and “not given” have been removed from this figure due to low amount of dams. The shares that have been pulled out of the circle diagram have been classified as natural migration barriers.**

Dams that had a total height drop between 0 and 1 m had the lowest proportion of dams classified as natural migration barriers (Figure 7). Of the dams that had a total height drop between 1.1 and 3 m had roughly 12-13 % classified as natural migration barriers. In dams that had a total height drop between 3.1 and 4.5 m there was a varied amount of natural migration barriers. The dams had a higher total height drop of over 4.5 m, 18-20 % were classified as natural migration barriers. For the four height classes, see figure 8 for their 95 % confidence intervals.

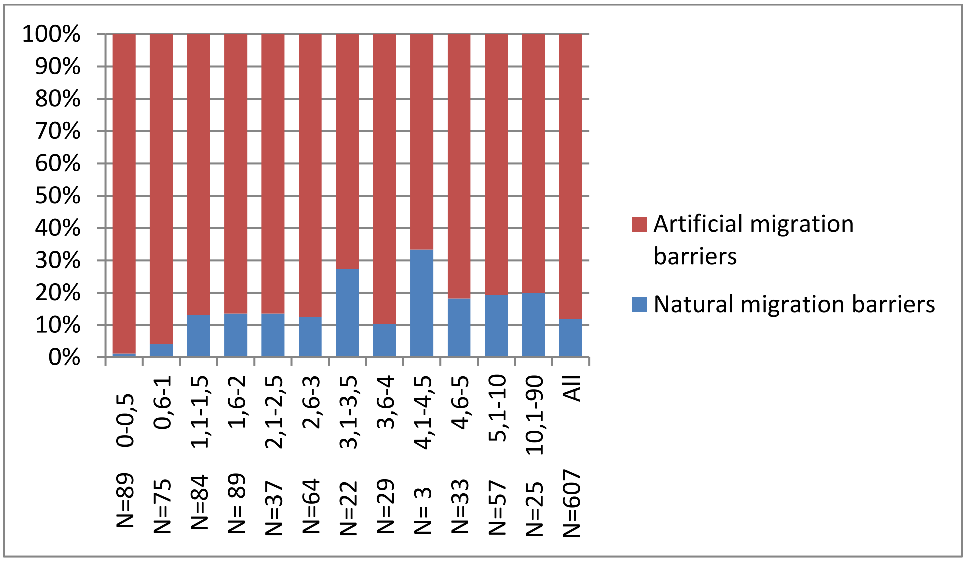


**Figure 7: Artificial and natural migration barriers for 607 dams. Dams have been sorted by total height of barriers (not always dam height) in steps of 0.5 m up to 5 m height. Dams that have a total drop height between 5.1 and 10 m represent one interval. All dams over 10.1 m have been sorted to an own interval. N represents the numbers of dams in each interval, note that there is a difference in number of dams in different intervals. Dams that have been classified as uncertain (N=2) have been removed from the figure. Dams that did not have a total height, have also been removed.**

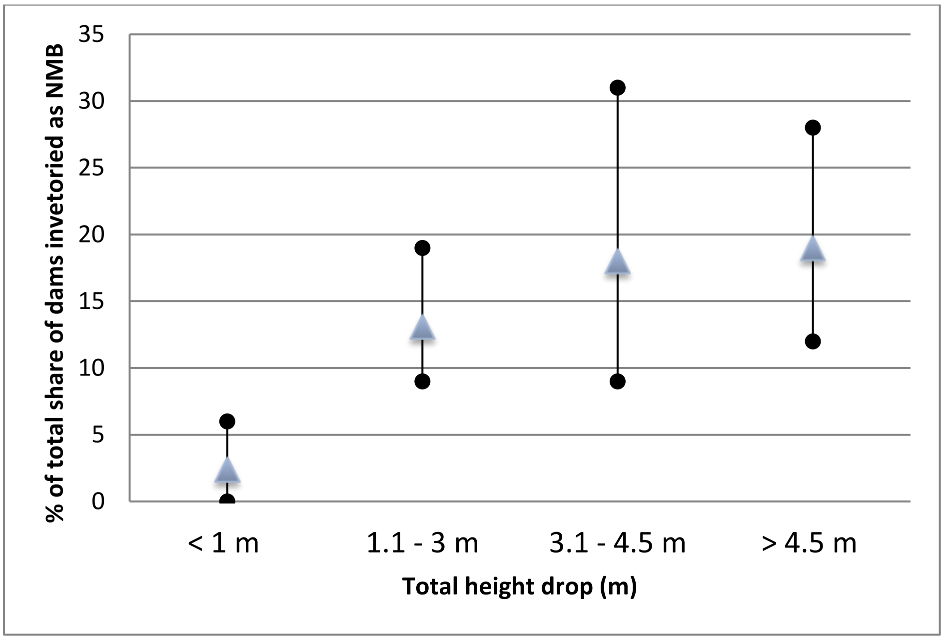


**Figure 8: Expected share of natural migration barriers by dams based on the data from habitat mapping in Värmland. Confident intervals (95 %) is based on number of dams that have been classified as natural migration barrier in different height classes. Number of dams in the analysis were 164, 274, 54 and 115 from the lowest to highest interval.**

Of the action proposals that are linked to the 72 dams classified as natural migration barriers, 50 dams had proposed actions that were linked to increase fish migration (Figure 9). Only 5 of them stated that nothing should be done, and 17 of them had no comment. For the 661 rapids and falls, there were 258 (39 %) action proposals that can be related to increased fish migration. For the 275 definitive migration barriers for trout in the class rapids and falls, there was 86 (31 %) suggested actions linked to increased migration or dispersal of fish. Furthermore, there was a variation among the survey personnel and how many natural migration barriers were being classed among the dams (which you would expect when different people make different assessment on various dams).

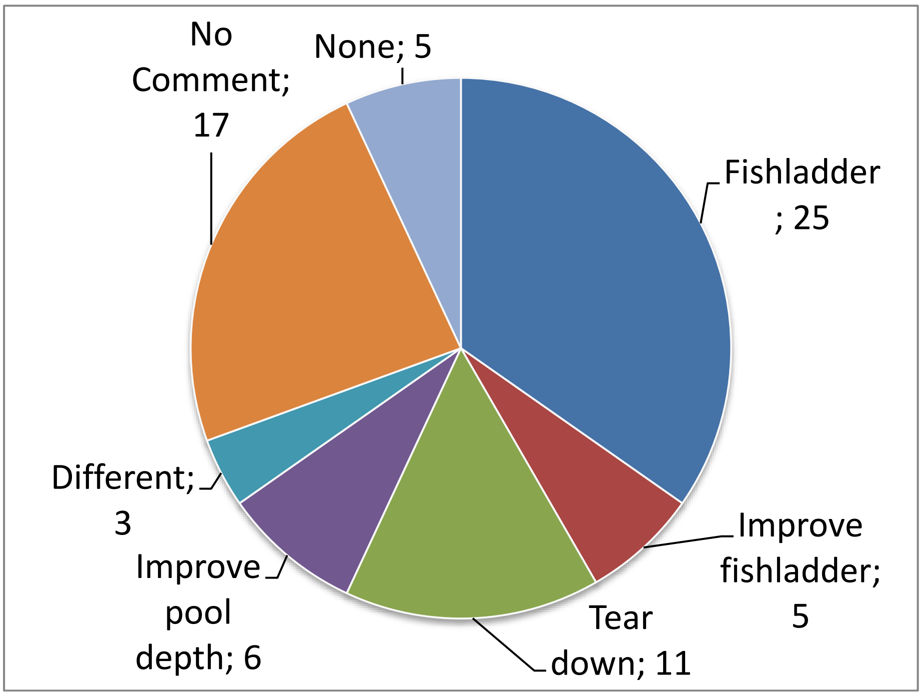


**Figure 9: Proposed action to 72 dams that have been classified as natural migration barriers. If there have been several actions suggestions to one dam, only one have been taken into account.**

## 6.2 Toponymy of water stretches

Four names almost always occur in the naming of water stretches that have a higher water velocity than the rest of the watercourse. As stated earlier these are: *current* (-ström), *rapid* (-fors), *fall* (-fall) and *cliff* (-stup). The greatest fall height in the shortest length can be found in water stretches whose names end in –*cliff* and –*fall* (Figure 10). Water stretches whose names ends in –*current* and –*rapid* have comparable slopes with each other and are both lower than –*cliff* and -*fall*. The sub-name can end with –*s* (-en, -et,), which can indicate if there have been one or more places where water have dropped on the route.

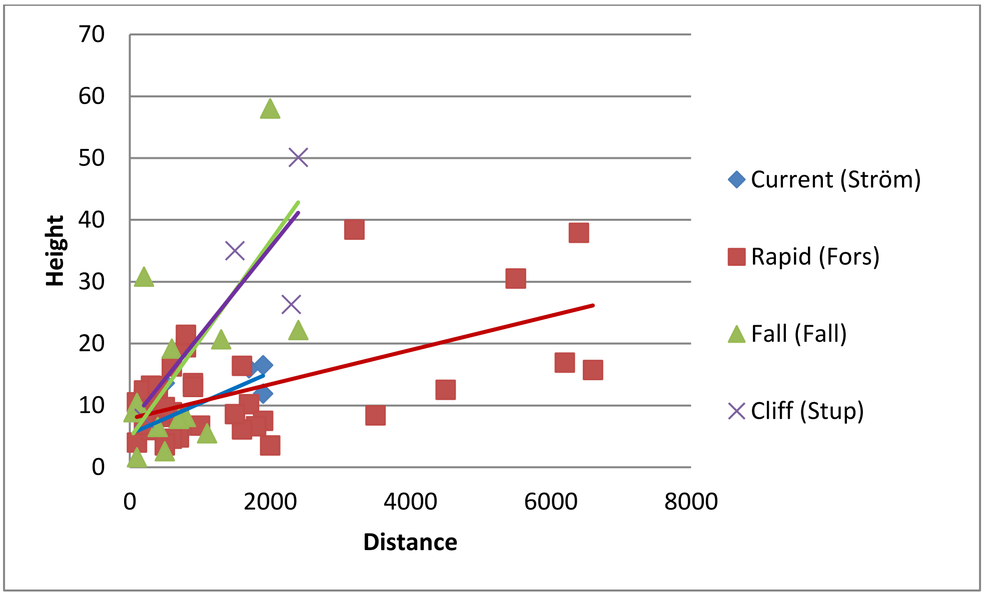


Figure 10: Fall heights and distances for different name endings for some water stretches in bigger rivers in Sweden. The coloured lines represent the best linear model for different endings.

## 6.3 Case study Horrmundsvalla

### 6.3.1 Names in the Horrmundsvalla catchment area

In total 218 names of places were collected of water surfaces and land surfaces in the catchment area. In Horrmundsvalla basin following names can be derived from fish and fishing: Abbornäs (Perch) , Idbäckssätern (Ide), Idbäckfjärden (Ide), Båthusviken (The Boathouse Bay) , Fiskbyvik (Fish village bay), Fisklösvik (No fish bay) , Magerabborrtjärnen (Many Perch pond), Mörttjärn (Roach Pond), Abborrtjärnen (Perch pond), Mjärdtjärnen (Trap pond), Gäddhån (Pike bay), Fisklösen (No fish), Idvik (Ide bay), Idtjärnen (Ide pond), Mörttjärn (Roach Pond), Gäddtjärnen (Pike pond) and Fiskbyudden (Fish village point). From these names, one could predict that the roach, perch, pike and ide are present in the catchment. All these fish are common species, and all are found in Lake Horrmunden. One can also state that traps have been used as fishing gear. The main fish caught with traps was pike and perch. There was also a tuft of grass in the water in the catchment area called braxentuvan (bream grass) (Riksantikvarieämbetet, Fornsök, 2015). The grass was called “bream grass” because of bream fishing. Since much of the catchment is present in Älvdalen’s Parish, the Elfdalians fish names were also examined for various fish species (Table 2). None of the fish names were Elfdalian. Furthermore, no names were found that derived from eel, bleak, whitefish, grayling and trout in the river basin.

Table 2: Swedish, Elfdalian and English names for some common fish species.

| Swedish | Elfdalian | English |
|---|---|---|
| Öring | Orad, Örad | Brown trout |
| Ål | Ål | Eel |
| Gädda | Gedda, Pilågedd,<br>Knaivstsiedsgedd,<br>Ljåskuogedd | Pike |
| Abborre | Abuorr, Kniktabuorr,<br>Kartabuorr | Perch |
| Mört | Mört | Roach |
| Id | Smoid, Gambelid | Ide |
| Braxen | Braks | Bream |
| Löja | Loga | Bleak |
| Sik | Saik | Whitefish |
| Siklöja | Blikta | Vendace |
| Lake | Latsi | Burbot |
| Harr | Arre | Grayling |

### 6.3.2 DNA of brown trout

COLONY identified no full or half siblings in any of the populations. Therefore, all individuals were retained for subsequent analyzes. GENCLASS placed 44 out of 57 (Q = 0.77) samples to the right fish location with the self-assignment feature (high value tend to indicate distinct genetic populations, 0.77 can be seen as a quite low value). Moreover, one individual was caught downstream of Horrmundsvallafallet which was more likely to belong to the upstream population. One individual in the downstream population could not be placed in neither the upstream nor downstream population. STRUCTURE identified the trout samples from Horrmundsvallen to most likely consist of two populations (K = 2, two clusters). The result from STRUCTURE visualizes how the upstream and downstream populations are related to each other using red and green colors (Figure 11). There is a larger element of green color upstream than the downstream population, but it is not a clear difference between the populations. One locus in the lower population deviated significantly from the Hardy-Weinberg equilibrium, however, the mean for all deviations from the Hardy-Weinberg equilibrium was not significant (i.e. not a significant deviation). $F_{\mathrm{ST}}$ and $G_{\mathrm{ST}}$ among the populations was 0.023 and 0.012. Expected heterozygosity ($H_e$) upstream of the fall was 0.62 and $H_e$ downstream was 0.65. Alleic richness ($A_R$) was 4.5 upstream and 5.2 downstream. Horrmundsvallens trout clusters near other trout from Dalälven River (Figure 12, 13).

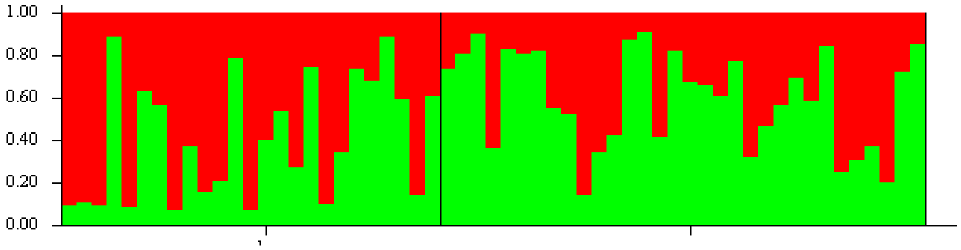


Figure 11: Results from STRUCTURE, 1 is the downstream population and 2 is the upstream population. One individual represent one bar and the color represent genetic clusters.

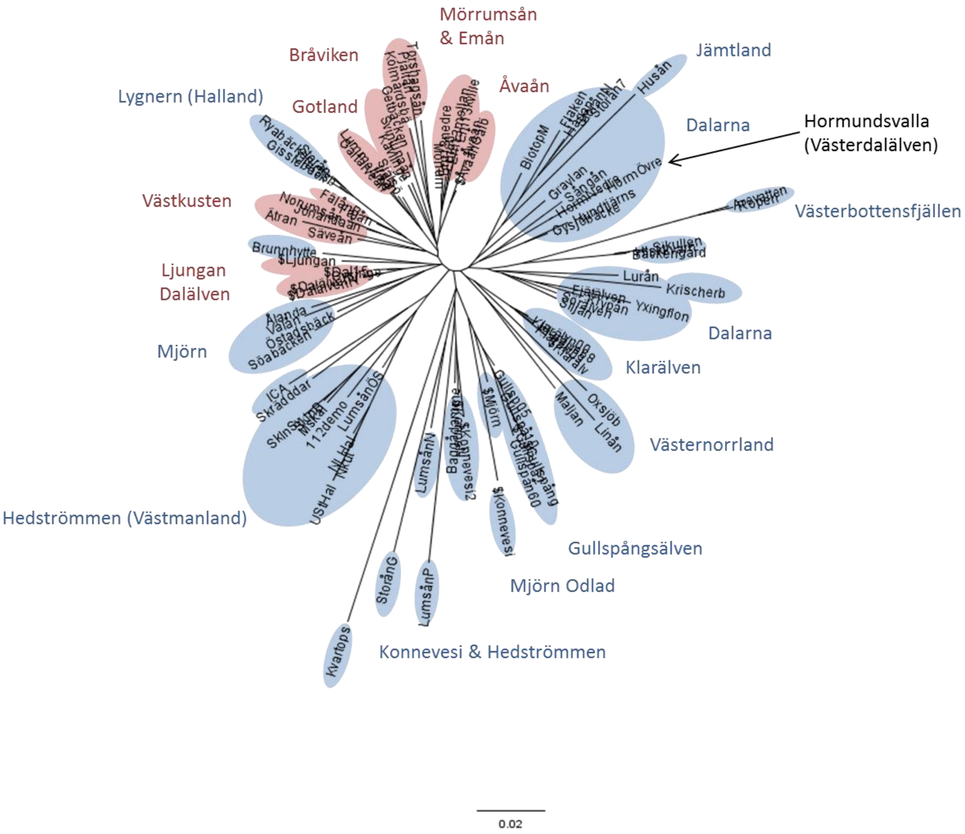


Figure 12: Dendrogram from 92 populations on Swedish trout (reference material) is constructed using "neighbour-joining" from chord distance (Dce) (Felsenstein, 2004). Sea migrating populations (red) and stationary or lake migrates (blue) and samples from fish farm (indicates with $). Horrmundsvalla is showed with an arrow.

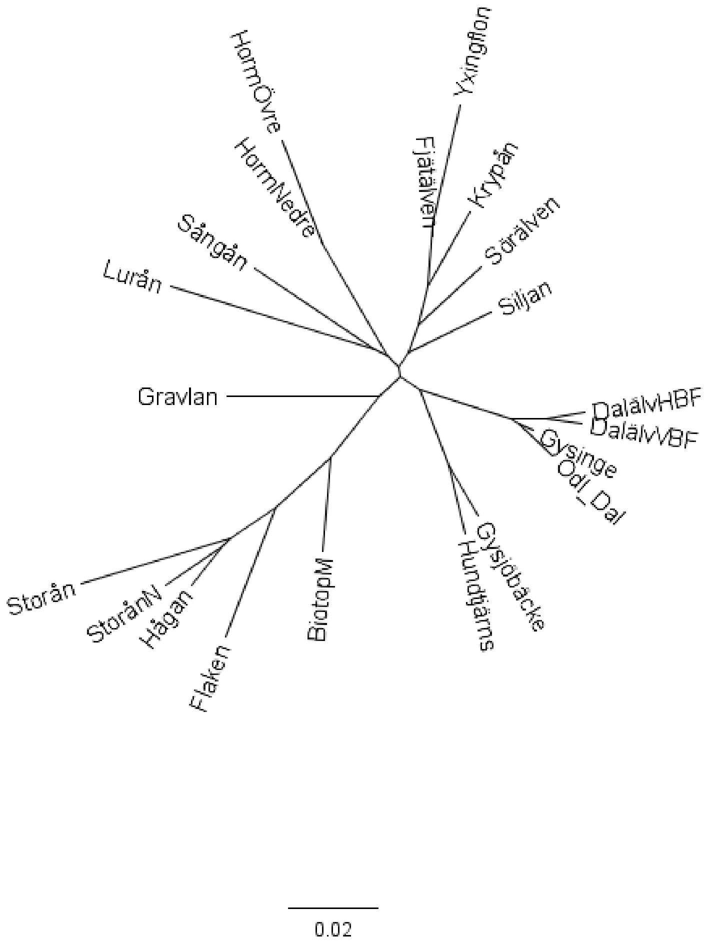


Figure 13: Dendrogram for trout in Dalälven River catchment area. HormÖvre and HormNedre indicates upstream and downstream population, respectively.

#### 6.3.2.1 Calculations of the effective population size and the loss of genetic diversity

The population upstream of Horrmundsvallafallet was too small to correspond to the loss of genetic diversity since 1870, i.e. a much lower genetic diversity was expected in the sample today. Thus it is not reasonable that the genetic difference ($G_{ST}$) between the two populations or the loss of genetic diversity have occurred since 1870, given the population estimates made (Table 3). The electrofishing showed 88.5 individuals per 100 m at the bottom of stretch 4, which is approximately 1700 m. Assuming that the trout density decreases by 5 %, 10 % or 15 % per 100 m upstream, the total population should consist of 1030, 737, or 553 individuals (Table 3,4). Based on the electrofishing and adoption of various $N_e$:$N$ ratios, $N_e$ should vary between 55 and 206 in the upper population. About 31 generations have passed since 1870 to 2015 with a generation time of 4.6 years. For $G_{ST}$ to increase from 0 to 0.012 over 31 generations an effective population ($N_e$) of 320 in the upper population is needed. Alternatively, $H_e$ should decrease from 0.655 to 0.618, an effective population ($N_e$) of about 270 is needed in the upper population, given all the assumptions mentioned in the method section.

However, the loss of genetic diversity, or the difference between populations ($G_{ST}$), coincides with when the hydropower plant was built in 1960 (Table 4). From 1960 to 2015, approximately 12 generations have passed with a generation time of 4.6 years. For $G_{ST}$ to increase from 0 to 0.012 over 12 generations an effective population ($N_e$) of 120 in the upstream population is needed. Alternatively, $H_e$ should decline to 0.618, an effective population ($N_e$) of about 103 in the upstream population is needed. That is a better explanation for the decrease in heterogeneity and an increase in $G_{ST}$ (Table 4).

Table 3: Populations estimates (*N*) and different $N_e$:*N* ratios for trout upstream of Horrmundsvallafallet. Expected decrease by loss of genetic diversity ($H_e$) since 1870. Alternative expected increase in $G_{ST}$ between the upstream and downstream populations in Horrmundsvallen since 1870.

| **Assumptions on decrease in habitat and assumptions on different $N_e$:*N* ratios** | ***N*** | **$N_e$** | **$H_e$** | **$G_{ST}$** | **Is it reasonable loss of genetic material since 1870?** |
|---|---|---|---|---|---|
| 15 % per 100 m. $N_e$:*N* 10% | 553 | 55 | 0,493 | 0,065 | No |
| 10 % per 100 m. $N_e$:*N* 10% | 737 | 74 | 0,531 | 0,050 | No |
| 5 % per 100 m. $N_e$:*N* 10% | 1030 | 103 | 0,563 | 0,036 | No |
| 15 % per 100 m. $N_e$:*N* 20% | 553 | 111 | 0,569 | 0,034 | No |
| 10 % per 100 m. $N_e$:*N* 20% | 737 | 147 | 0,589 | 0,026 | No |
| 5 % per 100 m. $N_e$:*N* 20% | 1030 | 206 | 0,607 | 0,019 | No |
| Theoretical pop. (corresponds to $H_e$) | | 270 | 0,618 | 0,014 | - |
| Theoretical pop. (corresponds to $G_{ST}$) | | 320 | 0,624 | 0,012 | - |

Table 4: Populations estimates (*N*) and different $N_e$:*N* ratios for trout upstream of Horrmundsvallafallet. Expected decrease by loss of genetic diveristy ($H_e$) since 1960. Alternative expected increase in $G_{ST}$ between the upstream and downstream populations in Horrmundsvallen since 1960.

| **Assumptions on decrease in habitat and assumptions on different Ne:N ratios** | ***N*** | **$N_e$** | **$H_e$** | **$G_{ST}$** | **Is it reasonable loss of genetic material since 1960?** |
|---|---|---|---|---|---|
| 15 % per 100 m. $N_e$:*N* 10% | 553 | 55 | 0,587 | 0,027 | No |
| 10 % per 100 m. $N_e$:*N* 10% | 737 | 74 | 0,604 | 0,020 | No |
| 5 % per 100 m. $N_e$:*N* 10% | **1030** | **103** | **0,618** | **0,014** | **Yes** |
| 15 % per 100 m. $N_e$:*N* 20% | **553** | **111** | **0,620** | **0,013** | **Yes** |
| 10 % per 100 m. $N_e$:*N* 20% | 737 | 147 | 0,629 | 0,010 | No |
| 5 % per 100 m. $N_e$:*N* 20% | 1030 | 206 | 0,636 | 0,007 | No |
| Theoretical pop. (corresponds to $H_e$) | | 103 | 0,618 | 0,014 | - |
| Theoretical pop. (corresponds to $G_{ST}$) | | 120 | 0,623 | 0,012 | - |

### 6.3.2.2 DNA comparison

$H_e$ and $A_R$ are expected to be lower upstream a barrier for fishes in the family Salmonidae (Deiner et al. 2007). Delta $H_e$ and Delta $A_R$ are the difference between upstream and downstream populations for each studied barrier in figure 14, 15 and 16 below. There are correlations between $F_{ST}$, Delta $H_e$ and Delta $A_R$ for all populations that are separated by barriers (Figure 14, 15, 16). Horrmundsvalla have one of the lowest $F_{ST}$, delta $H_e$ and Delta $A_R$ values compared with other studies of natural migration barriers and dams.

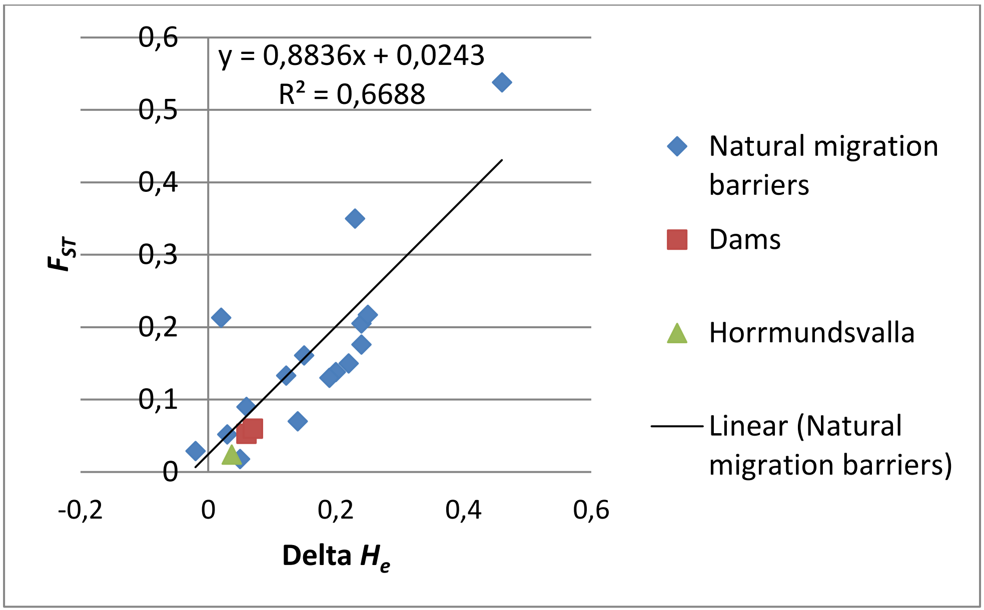


**Figure 14: Data from different studies on difference in DNA upstream and downstream waterfalls and dams on Salmonides. Delta $H_e$ is the difference between downstream and upstream population. $F_{ST}$ is measure for genetic differentiations between populations.**

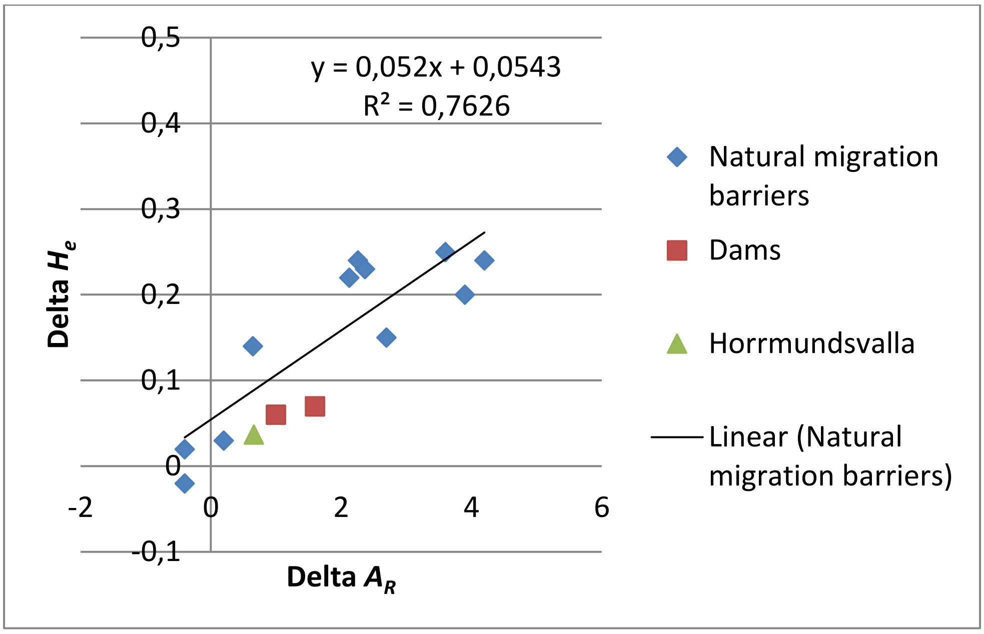


**Figure 15: Data from different studies on difference in DNA upstream and downstream waterfalls and dams on Salmonides. Delta $H_e$ is the difference between downstream and upstream population. $F_{ST}$ is measure for genetic differentiations between populations. Delta $A_R$ (allelic richness) is the difference between downstream and upstream populations.**

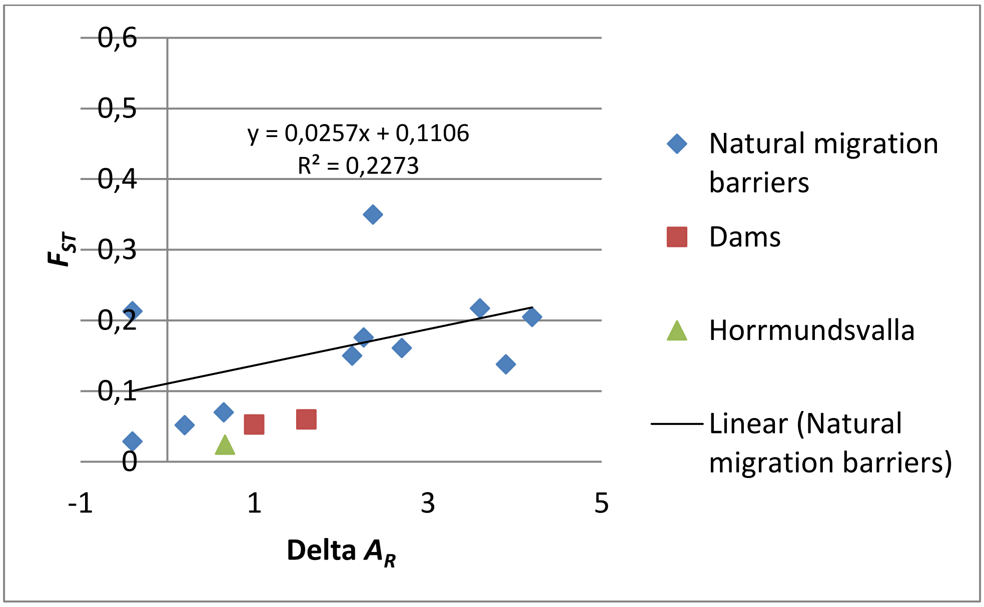


**Figure 16: Data from different studies on difference in DNA upstream and downstream waterfalls and dams on Salmonides. Delta $A_R$ (allelic richness) is the difference between downstream and upstream populations. $F_{ST}$ is measure for genetic differentiations between populations.**

## 6.3.3 Traditional methods

### 6.3.3.1 Log driving in Horrmundsvalla 1871 to 1960

1871 was the year that log driving in larger scale began in the Horrmundsvalla catchment area. Previously, the log driving occurred only for peoples own needs. Log drive buildings in Horrmundsvalla was mainly constructed in 1871 and 1874. Log drive buildings meant chests, weirs and dams to lead the timber in the watercourse (Figure 17). In 1883 regulations for the log dive activities in the catchment area were introduced to prevent nuisances and to increase efficiency of log driving, log drive inspector was Knight Lars Berg. The main nuisance around Lake Horrmunden was grazing beaches that were destroyed by timber. Concerning the fishing in the area it was stated that: "There are no fixed fishing buildings, however the fishing in the catchments lakes were and still are good and fruitful."

A description of the existing buildings in Horrmundsvalla watercourse was made in 1883. There were a number of chests and dams along the entire Horrmundsvalla. Horrmunds dam was in excellent condition and well built, the dam was 50 m long, 2.2 m high and 4 m wide. The dam had two spillways that both were about 6 m wide. There was an old dam below the new dam, which at the time served as a bridge. There was also scythe production just below the old dam in an iron mill. The iron mill was active between 1847 and 1913 (Björklund & Pettersson, 1982). The river used to form a complex of "islands" next to the iron mill. There was also a mill next to excavated material by the outlet. A saw was close to the iron mill, both the mill and the sawmill belonged to Horrmund's village.

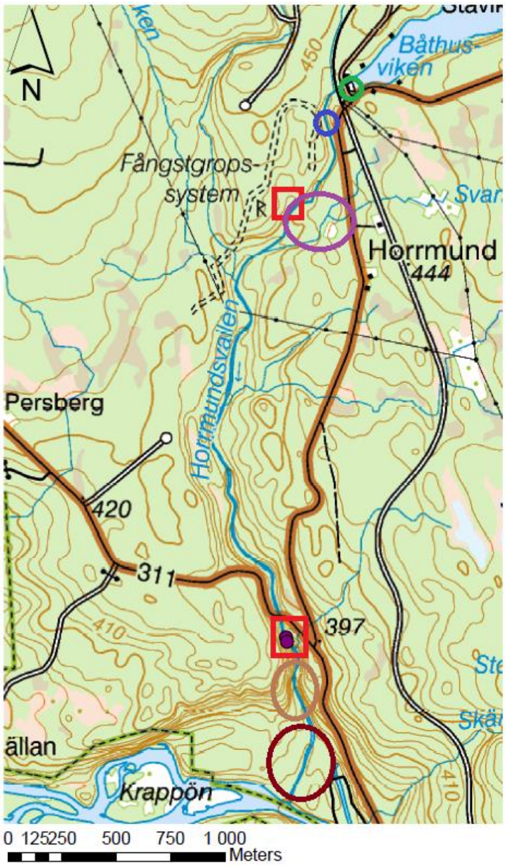


**Figure 2: Historic sites where one influenced the morphology or the water flow in the river. The green circle is the current dam and the first dam on the site was probably built in 1871 or 1874. The blue circle shows where the old dam was in 1869, year of construction unknown. Red squares mark where there were saws in the watercourse. The purple ring shows Horrmund's liebruk (scythe production site) and was active from 1847 to 1919. At liebruk the river formed a complex of islands. The light brown ring shows where there were blasts to clear the watercourse. The dark brown ring shows where blasts and cleaning of the river was done to create a new river path. Earlier Horrmundsvalla formed a delta at the Västerdalälven River. The two dots shows where Horrmundsvallafallet is located. Over Horrmundsvallafallet was a weir for log driving, years 1871-1960. The power station went into operation in 1960.**

There was a saw belonging to Resjövallen’s village next to Horrmundsvallafallet. The weir over Horrmundsvallafallet was at times 12 m wide and 21 m long.

To enable timber to float downstream Horrmundsvallafallet at lower water flows, a chests along a mountain ridge and a weir that is 10 m long and 7.5 m wide over a drop was needed. It was also proposed that a pool chest should be built and fills up the deepest pool. It was also suggested to blow up a stretch of 23 m.

It was also proposed to build a 350 m long chest on the left side along the river's new stream at the outlet. The use of explosives were also suggested for clearing the entry to Västerdalälven River.

The dam at the lake began to be worn out around 1915, so one considered to reconstruct the dam. However, in late April 1916 Dalälven River largest flood of the 20th century occurred (SMHI Knowledge Bank, 2010). At Västerdalälven below the Horrmundsvalla in Transtrand parish the water level was 139 cm above normal. The dam at Lake Horrmunden was damaged during the flood and was no longer suitable for log drive. The dam was probably renovated in late 1916 or early 1917.

The log driving lasted until 1960 when the hydropower plant was built. The last log drive was documented with camera by Mats Elfqvist from Älvdalen (Mats Elfquists collection movie No. 2, 1960). He illustrates the floating timber from Lake Horrmund in large collections over the falls and into Västerdalälven River.

### 6.3.3.2 Water rights and the base of the water rights permits

It is stated that the fish species in Lake Horrmunden were: pike, perch, roach, ide, bream, bleak, whitefish and restocked vendace, occasional trout, burbot and eel could be found in Lake Horrmunden. One can suspect that there is a definitive natural migration barrier for trout in Horrmundsvallen based on the basis of the water rights. However it is stated that eel migration will be blocked by the dam in Lake Horrmunden. Different types of stocks are suggested to the Lake Horrmunden to compensate the fish loss. For a full version of the water rights permits and the bases of the water rights, see Landsarkivet in Härnösand.

### 6.3.3.3 Historical pictures

Four historical pictures of the falls have been found (Figure 18, 19, 20, 21). Two of the photos are taken 1915-07-29 (SMHI, historical gallery, 2015). Figure 18 is from a postcard probably older than 1915, there are no small trees at the side of the fall compared to figure 19. The saw building, belonging to Resjövallens village could also be seen on the picture. The picture was taken in the spring when log driving activities occurred. Figure 19 shows a weir over the fall. Weirs were built to enhance the log drive. It is noted that upstream passage of trout and weak swimming fish species have not likely occurred over the weir. The smaller fall (Figure 20) shows no signs of human impact. The most recent historic picture (Figure 21) is taken in the summer, the saw building is no longer on the site. One picture was also found of the dam and the railway track over Horrmundsvallen (Figure 22).

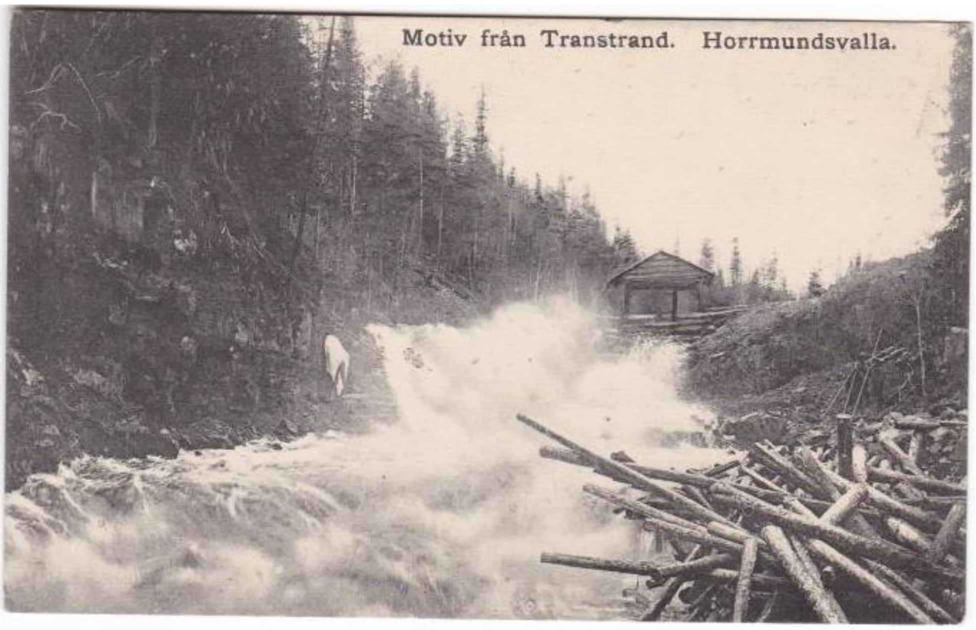


Figure 18: Horrmundsvallafallet, around year 1900. Picture from a postcard. Publisher: Er. Larsson, Transtrand.

Figure 19: Horrmundsvallafallet, the fall is affected by the log driving activities. A weir has been constructed to make the log driving easier. Stones have been places in the timber constructions. The picture is taken 1915-07-29 (SMHI, historiskt bildgarlleri, 2015).

Figure 20: Downstream Horrmundsvallafallet, one cannot clearly see that morphology of the water course has been altered drastically. Picture is taken 1915-07-29 (SMHI, historiskt bildgalleri, 2015).

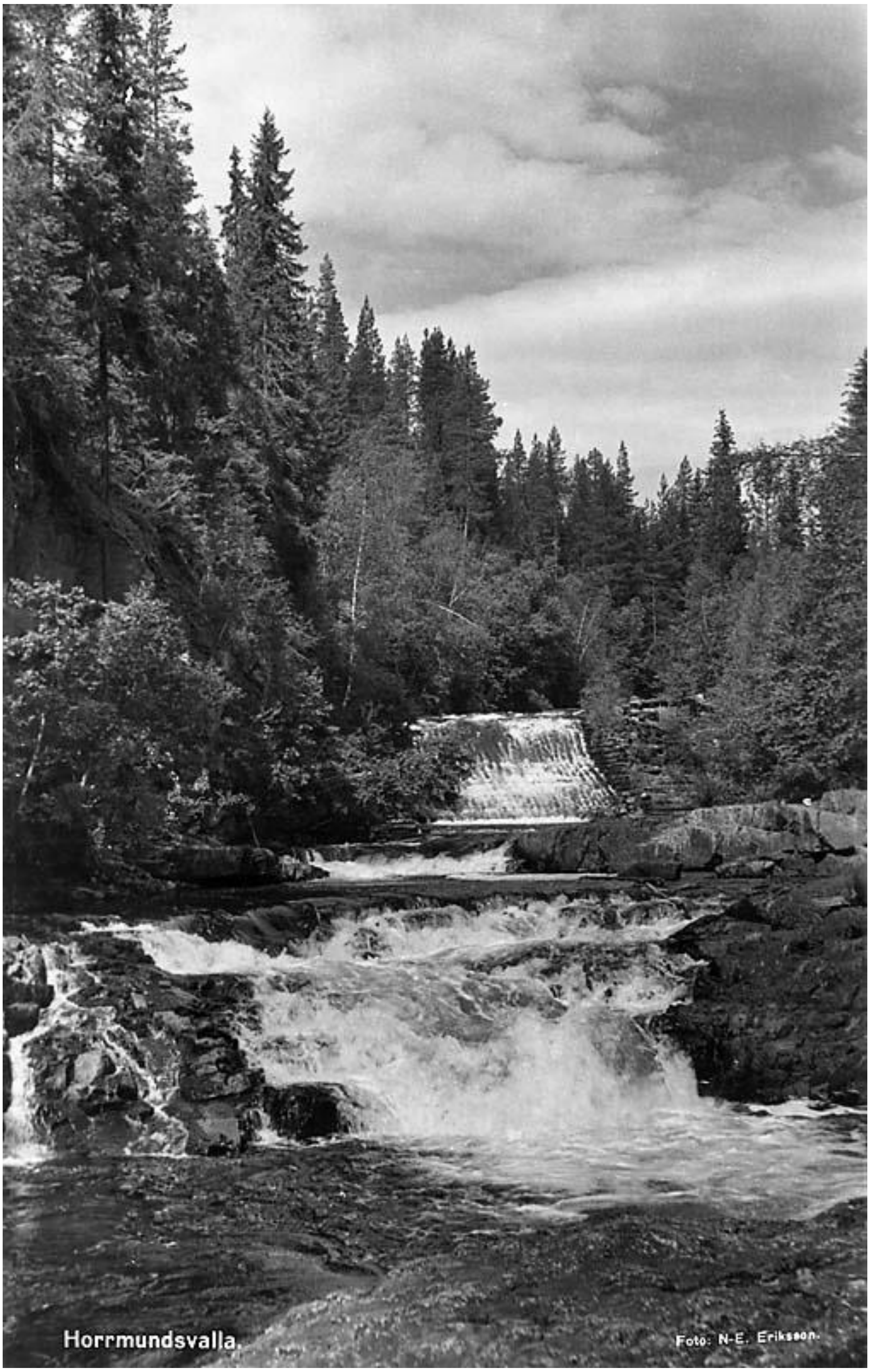


Figure 21: Horrmundsvallafallet, 1920-1939 by N-E Eriksson (Riksantikvarieämbetet, 2015)

**Figure 22: Railway bridge over Horrmundsvallen and the regulating dam by Lake Horrmunden. A person with dresin, picture taken around 1915 (Flickr, Tekniska Museet, 2015)**

#### 6.3.3.4 Interview

Sune Brändholm (chairman of Malung-Sälen fishing association) was interviewed about the fishing conditions in the catchment area. Since it is impossible for living people to be able to answer whether the trout have been able to pass the waterfall earlier than 1870 or not, so the question was not asked if trout has been able to pass the fall. However he confirmed that there has historically been a good fishing spot below the fall and that his father used to fish trout there. Furthermore, Mr. Brändholm did not know any place where trout fishing occurred upstream in Lake Horrmunden. In Björnån Strema there is only pike because it is a slow flowing stream. Furthermore, Brändholm did not know if it is possible that some trout could occur at the top of the river, but he had never heard anyone catching anything other than pike in Björnån Stream. He also told that there is much bream in the lake nowadays, one could get 50 pieces with fishing net that was in overnight and it is not uncommon to get perch over a kg in Lake Horrmunden.

#### 6.3.3.5 Curiosities

Name variations have occurred during the historical studies of Horrmundsvallen. Hormundsvalla, Hormundsvallen, Horrmundsvallsån, Horrmundsvalla and Horrmundsvallen are names that have appeared on the watercourse. Generally, one should probably expect a variation in name on rivers and lakes in historical studies.

#### 6.3.3.6 Field visit Horrmundsvallen

During the fieldwork six pieces of falls or rapids were found at stretch no. 3 (Figure 3). The first was about 1.5 m high and had been blasted, like the historical documentation from 1883 was indicating. The second step was slightly smaller than the first one; this one was also blasted. The third, however, was less affected than the first two. The fourth seems to be blasted, but significantly less affected than the first and second rapids. The fifth consisted of a small drop of about 1-1.5 m (Figure 20, 24). The sixth and last was the largest one on the route and is called Horrmundsvallafallet (Figures 18, 19, 21, 23). Rapids and falls 1-5 on the route are historically definite migration barriers to weak swimming fish species and partially passable for trout. Horrmundsvallafallet is and has most likely been a historically (before the weir, in 1870) definitive migration barrier to trout (Annex 1). A good entering approach (pool) does not exist at Horrmundsvallafallet and the trout have no chance to pass the waterfall. None of the previous migration barriers in the stream had the same high magnitude and often there were pools to rest in between the passages for trout. Horrmundsvallafallet is about 8 m high (measured by GPS).

**Figure 3: Horrmundsvallafallet today. The rod is 1.5 m high and is held somewhat above the water level to represent more natural water conditions.**

**Figure 24: Horrmundsvallafall at longer distance. Compare figure 21, note that the pictures are taken from different places.**

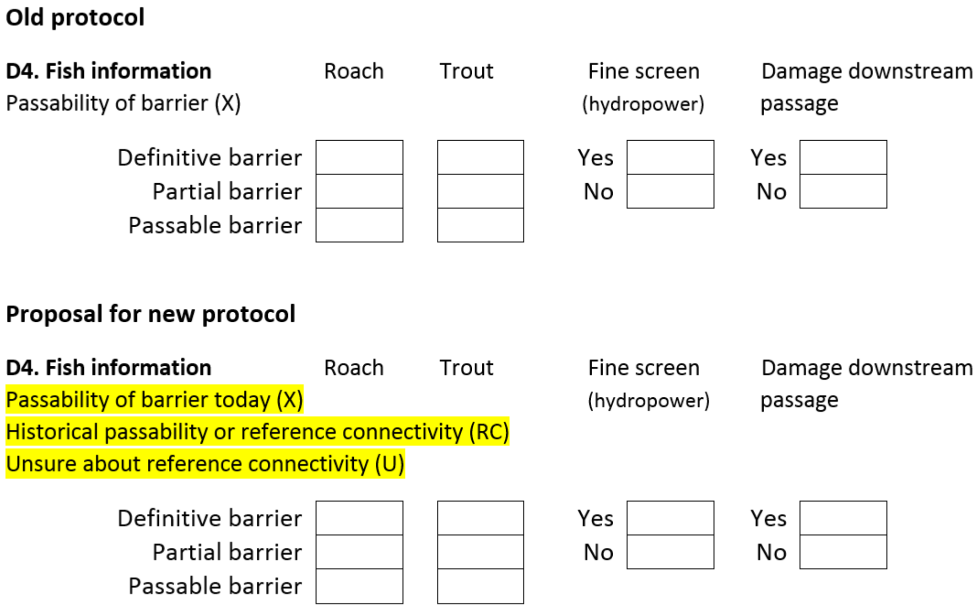
# 7 Discussion

## 7.1 Habitat Mapping

Halldén et al. (2002) admits that it may be difficult to get an idea if an artificial migration barrier has been a natural migration barrier solely through field visits, therefore one can choose “uncertain” in the field protocol. In Värmland’s habitat mapping, only two dams were classified as uncertain with respect to natural migration barrier. However, in the comment section, some notes were made that one did not know if the dam might have been a natural migration barrier or not.

There are action proposals to increase fish movement for 30 % of rapids and falls that are definitive migration barriers for trout from the raw data in Värmlands Habitat mapping. That should mean that the probability is 30 % that dams originally being a definite natural migration barrier for trout receive action proposals for fish migration. There are two more plausible explanations for why there is such high proportion of action proposals on dams that are classified as the natural migration barriers. One is that the location originally has been a migration barrier for some fish species but not for strong swimming species, such as trout. The second explanation is that it is an artificial migration barrier and therefore one should fix so that fish can pass the barrier, regardless the reference condition.

One possible explanation for the large proportion of possible actions related to natural migration barriers might be due to the migration barrier protocol. First, there is a check box in which one can propose possible actions at the site which will probably make the inventor instinctively assess what could be done related to fish migration. The second possible explanation is that there is no room for assessment of the historical passability at the current location (for natural migration barriers, dams). Many of the dams historically may have been definitely natural migration barriers for some species but not for all, this is not clear in the protocol. It is also important to highlight that a natural migration barrier does not say anything about the passability of various fish species. Therefore, the assessment of a natural migration barrier must be linked to the fish species that may possibly have been able to pass it historically (Figure 25). The suggested change shown in figure 25 will reflect this issue. This will likely tell how “many” dams that originally have been definitive natural migration barriers to trout. Actions associated with increased fish migration should be avoided. Furthermore, one will get an idea of how many fish species that may be affected by the migration barrier. These amendments to the protocol will probably cause proposed actions to have a better ecological relevance to the ecosystem, i.e. no proposed actions related to fish migration should occur at total natural migration barriers. Habitat mappings can capture parts of the natural migration barriers regarding the reference conditions at dams but probably not all, which also was suggested by Halldén et al. (2002).



**Old protocol**

| **D4. Fish information**<br>Passability of barrier (X) | Roach | Trout | Fine screen<br>(hydropower) | | Damage downstream<br>passage | |
|---|---|---|---|---|---|---|
| Definitive barrier | ☐ | ☐ | Yes | ☐ | Yes | ☐ |
| Partial barrier | ☐ | ☐ | No | ☐ | No | ☐ |
| Passable barrier | ☐ | ☐ | | | | |

**Proposal for new protocol**

| **D4. Fish information**<br>Passability of barrier today (X)<br>Historical passability or reference connectivity (RC)<br>Unsure about reference connectivity (U) | Roach | Trout | Fine screen<br>(hydropower) | | Damage downstream<br>passage | |
|---|---|---|---|---|---|---|
| Definitive barrier | ☐ | ☐ | Yes | ☐ | Yes | ☐ |
| Partial barrier | ☐ | ☐ | No | ☐ | No | ☐ |
| Passable barrier | ☐ | ☐ | | | | |

**Figure 15: Suggestion for how the migration barrier protocol should be changed to reflect the historical passability for different fish species. The old protocol was used in the inventory of migration barriers in Värmland. Passability of barriers today (X) should be combined with reference connectivity (RC) or unsure about reference connectivity (U).**

A total of 43 % of the dams had no function today (11 % of the total amount migration barriers). Many of the dams that have no use today come from the log driving era (County Administrative Board of Värmland, 2013). It must be seen as a surprisingly high proportion of dams which have no or limited purpose today. Extrapolating the results from Värmlands habitat mapping throughout Sweden means that about 4000 dams in Sweden have no use!

All but four culverts were classified as artificial migration barriers. It is a reasonable assumption that the majority of culverts in Sweden have not been natural migration barriers. In the category "blasted rock" 72 % were classified as natural migration barriers then one can conclude that many of these migration barriers historically probably belonged to the category rapids / falls and thus have been natural migration barriers.

Furthermore, as expected, there were a low proportion of dams classified as natural migration barriers of dams with a total drop of less than 1 m. There were 164 dams that had a total drop equal to or lower than 1 m, and only 4 pieces of dams were classified as natural migration barriers. Then it is reasonable that one should not expect to find many natural migration barriers of dams with a total drop height of 1 m or less. Furthermore, it is expected that dams which have a higher total height should have a higher share of natural migration barriers.

About 10 % of the hydropower dams were classified as natural migration barriers. This can be seen as a first estimate how many hydropower dams that may have been built by natural migration barriers in Sweden. As mentioned earlier, natural migration barriers do not say anything about which fish species that have been able to pass the rapid or fall. Presumably this is because some hydropower dams are built in places where a high head is utilized, probably 5 % to 10 % of hydropower dams have been built by definitive natural migration barriers for trout in Sweden. However, the share of hydropower dams that have been built at definite natural migration barriers to roach should be significantly higher than for trout.

## 7.2 Toponymy of water stretches

The slope of the linear function was steeper for guiding name for *cliffs* and *falls* than for *currents* and *rapids*. That alone indicates that the guiding names say something about passability. It is more difficult to pass water flowing stretches of the guiding names ending by *cliffs* or *falls*. However, there is nothing to be generalized, because Sweden's most famous waterfall ends by “*rapid*”, Tännforsen. *Rapid* names are probably a more universal, appearing on many different types of water flowing stretches. However, if a former waterfall has been called -*cliff*, one can strongly suspect that passability for many fish species have been limited. If the waterfall have one of the following descriptive names; *big*-, *hell*- or *steep*, one should also suspect that passability of various fish species have been limted. Laxhoppet (Salmon jump) in Umeälven River is an example of a waterfall where the name describes that salmon jumps here (passed). Identification of water flowing stretches says more than what many think when assessing passability for various fish species.

## 7.3 Case study Horrmundsvalla

### 7.3.1 Names in the catchment area

By examining different names in the catchment area one can get an idea of the different fish species and fishing practices that occurred historically. Names that trace to highly migratory fish species such as salmon or eel, then one can assume that any of these species has occurred in the area. That neither eel nor trout related name was not found in the catchment area cannot confirm that Horrmundsvallafallet has been a natural migration for these species. Perch, roach, ide, bream and pike are all species that are not particularly strong-swimming species and then then this would indicate that these species have been able to colonize the catchment from the Västerdalälven River. Because trout populations can appear as stationary in a river throughout its life cycle, trout related names become as an indication of historical occurrences (Spens, 2007). However, if a water surface had been called “spawning current” (lekströmmen) or other that can be directly related to spawning of salmonids, this could indicate that the fish could pass a certain location. All names, derived from eel can most probably demonstrate that it has been passable at the current location for eel (with reservation to Trollhättan Canal), since eel migrates from the Sargasso Sea and up in Swedish waters for growth.

As a method to examine the historic passability of different fish species between two sites, this should be seen as a low priority choice of methods for studying natural migration barriers. In this case, one could see the lack of trout related names in the catchment area could confirm that Horrmundsvallafallet has been a natural migration barrier for trout. But the chance of committing a false-positive result is high, that trout exists in the catchment area though no name proves it. However, fish related names say something about the habitat type in an area (Spens, 2007). In this case; roach, perch, pike, ide and bream were found. That fish related names could indicate that they have been able to colonize the habitat themselves, can be rejected, since a place may have adopted a name of a restocking event in the area.

Possibly in this survey, it is wrong to look at the names that can be related to various fish species. Perhaps, upstream of Horrmundsvallafallet, was a more or less empty fish basin. Then maybe No Fish (Fisklösen) and No fish bay (Fisklösvik) had been better names to describe what fish species did exist in the catchment area. To confirm that the catchment area has been more or less fish empty in the past, paleolimnology methods might answer this types of questions better.

### 7.3.2 DNA of brown trout

The result of the difference in DNA between the populations in Horrmundsvallen coincide with when the hydropower plant was built in 1960. On the one hand it could be interpreted as less water in Horrmundsvallen made it impossible for trout downstream to pass the fall. On the other hand, given that there is probably no trout habitat upstream of Lake Horrmunden it is reasonable to believe that the two populations formed the same population before 1960; the same conclusion as Dannewitz et al. (2012) did for Lake Mjörn. This would lead to the (probable) erroneous conclusion that trout passed upstream the weir, built around 1870. That is however probably an erroneous conclusion. However, this is out of the question, because there is a laminar water flow and the water velocity is too high.

The difference in $G_{ST}$ and the decrease in $H_e$ coincides with the hydropower plant construction but is most likely due to fish stocking upstream from both populations.

At least 26,000 1+ brown trout (unknown origin) have been stocked into Lake Horrmunden prior to 1960 (the construction of the hydropower plant prevented downstream dispersals of restocked trout). The earliest dams that were located in Horrmundsvallen were for log driving and regulation of the water to hydropower plants in Dalälven River. Water has gone from the lake through spillway to Horrmundsvallen and made it possible for restocked trout to find suitable habitat in Horrmundsvallen. Lake Horrmunden and the watercourses upstream is probably a very bad habitat area for trout. Flowing water is a prerequisite for a good habitat and spawning area for trout. Björnån Stream (upstream of Lake Horrmunden) is a slow flowing water with a vertical height of 70 m over a distance of about 45 km (average slope of 0.0015 %). In addition, there are pike established in the river and there is probably no trout population in the catchment area (except in Horrmundsvallen). The restocked material could only colonize downstream to Horrmundsvallen.

One can also consider that the stocked trout did not establish in Horrmundsvallen. But then the trout population upstream Horrmundsvallafallet needed at least to have an effective population size between 270 and 320 to correspond to the reduction in $H_e$ since 1870. The most advantageous conditions are still lacking 70 $N_e$, a trout density reduction of 5 % per 100 m and an $N_e{:}N$ ratio of 20 %. But it is unreasonable that the stocked material did not have an impact, as there is a surprisingly high $H_e$ in both populations compared with other trout populations in Sweden (Östergren, 2015).

One expects differences between $A_R$, $H_e$, and $F_{ST}$ (indirect $G_{ST}$) among populations that are isolated by waterfalls and dams (Figure 17,18,19) (Deiner et al. 2007). The factors that control how big the difference is; $N_e$ upstream and downstream, time (how long they have been isolated), and if they have contact with other populations either upstream or downstream. A much larger difference was expected in $A_R$ and $H_e$ between the populations to be able to say for "sure" that both populations have been isolated for a long time. Usually the case for natural migration barriers to Salmonidae is that downstream population have higher $H_e$ and $A_R$ than upstream population. If not, then one should investigate what is the cause; habitat size, $N_e$, contact with other populations, restocks or isolations?

The dendrogram (Figure 15) indicates that stocked material in Lake Horrmunden probably is from Dalälven River catchment area. Possibly it consisted of the downstream population because it was easy to catch trout there. But it is not plausible that there are "genuine" Horrmundsvalla trout in the system, with such high $H_e$ in both populations. The stocked material did probably not consist of any of the already "known" restocked materials such as Lake Siljan trout.

The assumption that the downstream population has no loss of genetic material ($H_e$), seems to be reasonable when one trout from the lower population could not be placed into either the downstream nor upstream populations. This suggests that the downstream population have contact with trout from the Västerdalälven River. That no upstream migration of trout has happened since 1870 is also a reasonable assumption. The other two assumptions are probably a bit more uncertain. A generation time of 4.6 years is based on an estimate of Lake Lygnern and Lake Mjörn (Dellefors & Dannewitz, 2007; Dannewitz et al. 2012). One can assume that generation times are longer in Dalarna, because of the warmer climate in Lygnern and Mjörn. The assumption that trout populations had the same $H_e$ at isolation time is probably an erroneous assumption. Since isolation of populations by natural migration barriers probably occurs in stages (i.e. does not occur from one year to another).

It has been shown in this study that one must have very good track of stocking history and historical conditions, in order to be able to assess if a hydropower plant have been built by a definitive natural migration barrier or not. It is also incredibly important to know the effective population size of the system to be able to say anything about how long the population has been isolated. The assumptions for $N_e$ are based on the electrofishing and is regarded as the biggest uncertainty in this study. With a higher number of electrofishing locals upstream, it would be possible to a better estimate of the $N_e$-value of the population. Alternatively, one could take more DNA samples from trout upstream. Habitat quantity and quality is what control how large $N_e$ can be in a system. More genetic research on trout populations that is isolated by natural migration barriers and habitat size that controls $N_e$ in the populations is needed. Stochastic gene flow downstream of natural migration barriers is something that is unexplored and is a factor for the downstream population development.

### 7.3.3 Traditional methods

It is important to combine relevant historical information with current information about the location, and then make an assessment about which fish species that passed the site. It isnot possible to assess historical passability based on a historical picture or single historical sources of the passability of different fish species, alone. Historical pictures can be very difficult to interpret (heights, lengths, water velocity, etc.) and they do not say anything about the pool conditions.

There is nowhere explicitly stated that Horrmundsvallafallet is a definitive natural migration barrier to trout, but there are several historical arguments for this:

- First, there was a discussion between stakeholders prior the construction of the hydropower plant that there was two populations of trout in Horrmundsvallen one over the weir and one in contact with the Västerdalälven River. Trout population upstream of Horrmundsvallafallet is virtually isolated from the weir with steep cliffs and the dam at Lake Horrmunden.

- Second, experts (fiskeriintendenten and the freshwater laboratory) argues that the eel migration to the lake will be impossible when the hydropower plant is in operation. To discuss upstream migration of eel and not trout means that they probably reflected on that the Horrmundsvallafallet was a definite migration barrier to trout.
- Third argument, historical catch was about 150 kg trout per year in the lower part of Horrmundsvallen with rod. Which is also confirmed by Sune Brändholm. During the field visit this was considered reasonable, when there were many pools where trout probably rested between passing falls and rapids (assuming that trout could not pass a certain place).

From the log drive movie one get a very good understanding of how high Horrmundsvallafallet is and the smaller falls and rapids in Horrmundsvallen. The falls in Horrmundsvallen must have been difficult to pass for trout based on the film. The film was a better way to get an idea if trout has been able to pass Horrmundsvallafallet, or not, than the historical pictures in this case study, according to me.

There are some arguments that could be interpreted as that Horrmundsvallafallet has been passable for trout. There was trout stocking in Lake Horrmunden, therefore, Västerdalälven River trout must have been able to pass the fall.

There was historical trout catches in Lake Horrmunden, therefore, Västerdalälven River trout must be able to pass the fall (assuming that there is probably no trout habitat upstream in the catchment area).

What speaks against the two above arguments is that stocked trout in the lake was something that was requested because of the increased recreational fishing and pike compensation was no longer necessary because the residents in the area were no longer as dependent on fishing for consumption.

Catch data on trout was from 1963 to 1968 at which time the hydropower plant had been operating for 3 years (thus making it impossible for upstream migration of trout because of the dam). Catch data on trout coincides well with the stocking data from the period.

In summary, there are strong arguments that trout have not been able to pass Hormundsvallafallet. It was also sad that trout in Horrmundsvallen would die out because it would completely dry out some periods when the hydropower plant was finished. It turned out to be wrong because that is the trout population sampled.

## 7.4 Horrmundsvalla

### What fish species has passed the falls before the weir in 1870?

Since upstream migration of eel has been discussed and eel has been caught in Lake Horrmunden, eels must have been able to pass Horrmundsvallafallet? An answer for this can be found if one reflects on the biology of eel. Eels are poor swimmers, their maximum swimming speed are two to three body lengths, which is about 0.8 to 1.25 m/s for a 40 cm eel (Calles et al. 2013). Eel have no ability to jump like salmon. It is only the small eels that have a good chance against vertical damp surfaces (climbing up) (Calles et al. 2013). At the river mouth of Dalälven River, Älvkarleby eel collations have been done since the 1950s. It turned out that the upstream migrating eels had an average length of 40 cm at Älvkarleby (Wickström 2002). At each natural migration barrier (all old rapids and waterfalls) that existed in Dalälven Rivers and Västerdalälven River, the upstream migration was probably stopped or delayed, and a large number of eels never continues to the "top" of the catchment area. Despite the historically large eel population that has existed in Sweden, it's probably the wrong mindset that eel can pass any natural migration barrier (even those are slowed and stopped by natural migration barriers, among others Trollhättefallen). Migration time from Älvkarleby to Transtrand would probably take 2 years (Håkan Wickström, SLU, personal communication). Then one can add about 10 cm in length on those eels who managed to get high in the system (Håkan Wickström, SLU, personal communication). The water velocity during historical conditions over many of the

Figure 26: Distribution map for European eel in Sweden (green). Red area denotes Horrmundsvalla catchment area where there is high chance that the eels could not colonize the area because of natural migration barriers. Distribution map (green area) from Clevestam & Wickström, (2008).

smaller falls in stretch three will probably be greater than the critical limit of what eel can swim. My conclusion then is that Horrmundsvallafallet / falls is a definitive natural migration barrier for eel (Figure 26). One cannot be absolutely sure that eels that were caught between 1910 and 1940 in Lake Horrmunden have not been able to get up to the lake by their own. Because no stocking history of eel has been found for the river catchment (stocking history have been found for 1952 and 1953). If eels could pass Horrmundsvallafallet they must have passed the weir, something Håkan Wickström sees unlikely. If stocking of eels can be confirmed between 1910 and 1940, then one can with higher confidence confirm that eels have not been able to pass the falls in Horrmundsvallen. Domnarvet was the first dam that dammed up Dalälven River (1870), and thereby blocking all eel migration upstream. It is prior to Domnarvsforsen being exploited which is considered as a reference condition for eels in this study.

With the adoption and knowledge they had at the time they built Horrmundsvalla hydropower plant and suggested compensation, one can both say that trout most probably was not able to pass Horrmundsvallafallet and eel migration most likely did not occur in Horrmundsvallen.

### Have bream been able to colonize Lake Horrmunden naturally?

Bream is the fish species which completely dominates in Lake Horrmunden today. Bream is one of our most weak-swimming fish species in Sweden (Calles et al. 2013). In a review of historical fish data from 1860 to 1911 it was found that bream mainly existed in eastern part and under the highest shoreline in Sweden (Schreiber et al. 2003).The maximum altitude bream found was at 347 m above sea level (Schreiber et al. 2003). In a comparable survey made in 1996, breams were found at 488 m above sea level (more lakes in 1996) (Schreiber et al. 2003). In the historical survey, a majority of bream lakes were encountered below the highest coastline and in southern Sweden, 98.2% of bream lakes. The remaining bream lakes (1.8 %, 10 pieces) were encountered in lakes above the highest coastline and in the northern region. That said, it is noted that the bream had a limited dispersal opportunity in the North and over highest shoreline. Lake Horrmunden is located at about 440 m above sea level and in the northern region. Horrmundsvalla have several falls that today are impossible for weak swimming fish species to pass. The critical stretch 3 (Figure 3) is approximately 500 m long and has a total drop of about 50 m, giving an average slope of 10 %. The most favourable condition for colonization for bream with respect to the slope of the watercourse would probably be just after the ice cap retreated. The bream is a fish species that prefer warmer water (Schreiber et al. 2003). Thus colonization was not likely under the most favorable slope conditions. Thus, bream could not have colonized Lake Horrmunden through Horrmundsvallen and thereby should not be in the lake fauna according to the reference condition.

## 7.5 Proposed measures at Horrmundsvalla

That Horrmundsvallen would have poor ecological status is correct if it is the reference condition one is comparing with. It is impossible to recreate the reference condition without removing the dam and restore from the log drive era. But that is not the idea with the status classification of water bodies in Sweden. It is probably more important to call the river what it is, a heavily modified water body.

Is connectivity needed (i.e. fish ladders or bypass channels) between Västerdalälven River and Lake Horrmunden? No, it is a natural conclusion that it is not the solution to achieve good ecological status or potential in the watercourse. It would create dispersal opportunities that are unnatural for the catchment area and it can be seen as something negative from an ecological perspective. Trout is isolated between the dam and Horrmundsvallafallet. But since most probably no other trout habitat or trout populations upstream the dam exists, one can question if trout has to migrate upstream or if it will migrate/disperse upstream. If the trout would be able to migrate upstream, it can be an ecological trap, because there are no suitable habitats upstream and the trout might not return to the watercourse (predation or stochastic event).

The most important thing to try to achieve from an ecological perspective in Horrmundsvalla is to not spill high flows in the "dry furrow". The system in Horrmundsvallen today is "adapted" to the local runoff downstream the dam. High flows flushes away epiphytes from the system and probably some 0+ trout falls over the fall. Also there is a high risk for stranding of fish when the spillways are closed (hence the low number of trout during the electrofishing compared to 2006). Today, the average water flow in Horrmundsvallen is 0,420 $m^3/s$ at the mouth of the river to Västerdalälven River.

**Minimum discharge?**

No water spillage has occurred in the stream since at least 2003 to 2006-11-26 (older spillage data is not available), i.e. trout which was electrofished in Horrmundsvallen 2006-08-29 had made it with local runoff. If the electrofishing made in 2006-08-29 will be the reference condition for zero spillage in Horrmundsvallen, there should be about 30 trouts / 100 $m^2$ corresponding to reference condition (at the same electrofishing locale). To measure how much more trout Horrmundsvallen will get with eg 5 % (0.2 $m^3/s$) minimum discharge one would first have to wait so that the trout in Horrmundsvallen can recover to levels that are not affected by the spillage in the mainstream i.e. hopefully levels comparable to 2006 (deterministic population development). Then consider minimum discharge e.g. 5% in Horrmundsvallen. To measure the impact of minimum discharge, a monitoring program should be set up (suggestive electrofishing). If minimum discharge is applied at once in Horrmundsvallen, one can impossibly know what effects it has on the system because it is affected by spillage. One cannot tell if it is habitat quality or quantity of water that is limiting the trout population in Horrmundsvallen.

There is water throughout the “dry stream” from the dam at the lake to Västerdalälven River due to a stream that enters Horrmundsvallen just downstream of the dam. Just because it is a “dry stream” does not mean that it's just dry and lacks biological values (Renöfält et al. 2015). The biological values at Horrmundsvallen can be seen as trout upstream and downstream of Horrmundsvallafallet. Grayling, minnow and bullhead were also found downstream the fall. The largest biological values in Horrmundsvallen is probably not directly related to the hydropower or status classification of the watercourse. On stretch three, with its many falls and rapids, there was an interesting cryptogam fauna, consisting primarily of mosses and liverworts on moist and shadow rock faces (an interesting cryptogam habitat in Sweden). Then one should ask if more water in Horrmundsvallen could contribute to a better local climate (humidity) for the cryptograms or not.

**Fish Compensation to ecological compensation**

Based on the information about the watershed and stocked trout in Lake Horrmunden, suggestively that the stocking of trout in the lake should end. Freshwater laboratory's earlier investigation, that the stocking of trout in the lake is not effective is probably right. At a working meeting between Fortum Generation and the regulator (Dalarna County Administrative Board with support from the fishing investigation group (Fiskeutredningsgruppen), County Administrative Board of Västernorrland) in 2014 on how some fishing related operating conditions are being applied, it was proposed and it was decided that the fishing compensation in the form of release of trout in the lake should be replaced by another fishing management measure within the same cost bracket. This is a more efficient application since resources can be directed to measures where they are more ecologically beneficial. Continued trout restocking lacks ecological importance of the current water system. Regarding stocking of trout in Västerdalälven River, suggestively that even this can be exchanged for another equivalent fishery conservation measure in the Västerdalälven River system.

# 8 Applications

Here is an "overall methodology" one can use to examine what fish species that have been able to pass a migration barrier. Furthermore, it is now know that one does not need to examine all the dams in more detail. Dams that have a total height drop less than 1 m is most likely not a natural migration barrier. It is also know that a majority of culverts most likely have reduced connectivity. The proposed changes in the habitat mapping template should be used to get a more accurate picture of the impact of migration barriers on fish fauna. Template used today is not satisfying to describe the impacts of migration barrier on fish fauna.

The information of historic passability is very important for priorities of connectivity restauration project in rivers!

# 9 Own reflections

What is the concept of connectivity? "The ability to disperse and free passages for animals, plants, sediments and organic material in upstream and downstream direction, and from the river to the surrounding land areas, in relation to the reference conditions" (HaV, 2013). Is the "disperse and free passages" reference conditions when there are so many natural migration barriers, which Värmland habitat mapping indicates? There were 57 of 478 (12 %) streams that had passable migration barriers (no migration barriers, both artificial and natural) for trout. What is a reference condition? Perhaps it is more common that natural migration barriers exist in our waterways that prevent disperse of fresh water fauna? Clearing for log drive has been widespread throughout Sweden. The Värmland habitat mapping indicates that extensive blastings have occurred in the water courses, 7 % of the migration barriers. That 72 % of those were classified as natural migration barriers, i.e. former rapids and falls before the impact (though “blasted rock” have not been investigated more comprehensively in this study). It may also be that many of the "blasted rock" barriers have worsened the dispersal opportunities for certain fish species because water velocity increases by channeling. It was identified that “blasted rock” in Hormundsvallen made it easier to pass a rapids chest. A relevant scientific question to be answered is how many of the waterways in Värmland County (suggested, because they have good data from there), have free dispersal of trout and roach respectively as a reference condition?

Natural migration barriers will determine how freshwater fauna will develop with time, because the fish fauna will be limited by natural migration barriers and all natural migration barriers have different conditions for various fish species to disperse or migrate. Then the local freshwater fauna will develop to a "unique" composition of fish species. Then a natural migration barrier is a key element in the aquatic environment that should not be built off by a bypass channel (i.e. wrong custom bypass channel including more fish species than the reference condition). Lack of connectivity is something that is often stated as an argument for the construction of a bypass channels or fish ladder. But there is no parameter in the status classification that takes into account if a lake has more fish species in the system than the reference condition. A new concept in water management is needed:

**Over connectivity -** disperse and passages for fish fauna (because fish fauna are the main parameter in the status classification system) at a level that exceeds the reference condition (my definition).

**Reduced connectivity -** disperse and passages for fish fauna (because fish fauna are the main parameter in the status classification system) at a level which is below the reference condition (my definition).

Why introduce new concepts? The reason is to reflect the reference condition in the system. Shall bypass channels or fish ladders for all occurring fish species really be done?

What will the ecological consequences be if one choose to remove an old log drive dam when many of the natural migration barriers in the stream already have been blasted away (as many of the rapids in Horrmundsvallen)? There is probably no one today who can tell if **over connectivity** in our water could be a large or small phenomenon. However, it is know that there are approximately 11 000 dams in Sweden (affecting connectivity in various ways, but fish fauna passage is not always the best or only solution).

The issue of **over connectivity** may be investigated better if the new template for fish passages is applied in the habitat mapping method. There are many places where natural migration barriers have been removed, where the result has been **over connectivity**. It may have been unconsciously e.g. Trollhättan Canal. Jockfall in Kalixälven is a good example where it was made on purpose with a fish ladder over the fall.

# 10 Conclusions

Current methodology (habitat mapping) is not sufficiently satisfying to capture natural migration barriers at artificial migration barriers. Proposed template improvements should be implemented to increase assessing quality by artificial and natural migration barriers. If additional investigations of migration barriers are needed, one can follow the methodology presented here for Horrmundsvallafallet. This would likely give an estimate closer to the truth regarding the historical passability for different fish species. One will never know for sure which historical information that can be useful for assessing the historical passability at natural migration barriers. Yet historical information is necessary for a reliable assessment of historical passability at artificial migration barriers. Scientific methods such as DNA analysis on fish can provide some information about the migration barrier but it is appropriate to always investigate historical stocking of fish as well.

When there are historical total natural migration barriers at artificial migration barriers, then one does not need to build bypass channels or fish ladders. How many historically natural migration barriers there are at artificial migration barriers, is difficult to say. But more than 5 % could have been built by definitive historical natural migration barriers to trout by hydropower plants in Sweden (over 100 pieces). Finally, my conclusion is that Horrmundsvallafallet was historically (before 1870) a total natural migration barrier to all fish species, even at natural water flows.

# 11 Suggestions for further studies

I. Investigate the reference connectivity for streams in Värmland County for trout and roach separately. How many streams in County of Värmland have free dispersal for roach and trout as the reference conditions? How many places have **over connectivity** (improved passability for different fish species to spread upstream a natural migration barrier)?

II. A brief prediction of different distributions of fish species in Sweden based on natural migration barriers. I have not seen any study from Sweden that takes natural migration barriers into account when assessing the historical distributions of various fish species. Often only historical restocking has been taken into account where a fish species has been found in a basin.

III. Detailed study of passability for various natural migration barriers of various salmonids. How many manage to pass different kinds of natural migration barriers? One could combine passability (radio tags) with genetic methods. It is also very important to describe the barrier in detail so the work can be implemented to historical assessments.

IV. In the historical studies of Horrmundsvalla, detailed maps of the riparian vegetation of Lake Horrmunden were found. Maps are available both before and after the construction of the hydropower plant. How does the riparian vegetation appear today around Lake Horrmunden? The same thing applies to fishing conditions, information is available on the fishing conditions before and after the hydropower plant. How does the fish fauna appear today in Lake Horrmunden 56 years after the hydropower plant was built?

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# 14 Appendix

| Species | Barrier | Comments | NO. microsatellite | HoΔ | $F_{ST}$ | Reference |
|---|---|---|---|---|---|---|
| **Oncorhynchus mykiss** | Waterfall | waterfalls, 3 m each | 22 | 0.24 | 0.205 | Deiner m fl. (2007) |
| **Oncorhynchus mykiss** | Waterfall l | 21.3 m waterfall | 22 | 0.17 | 0.138 | Deiner m fl. (2007) |
| **Oncorhynchus mykiss** | Waterfall | 6.1 m waterfall | 22 | 0.1 | 0.213 | Deiner m fl. (2007) |
| **Oncorhynchus mykiss** | Waterfall | 6.7 m waterfall | 22 | 0.02 | 0.029 | Deiner m fl. (2007) |
| **Oncorhynchus mykiss** | Waterfall | 21.3 m cascade | 22 | 0.22 | 0.217 | Deiner m fl. (2007) |
| **Oncorhynchus mykiss** | Waterfall | 12.2 m waterfall | 22 | 0.17 | 0.161 | Deiner m fl. (2007) |
| **Oncorhynchus mykiss** | Waterfall | 6.1 m waterfall | 22 | 0.1 | 0.052 | Deiner m fl. (2007) |
| **Oncorhynchus mykiss** | Dam | Built 1982 | 22 | 0.06 | 0.053 | Deiner m fl. (2007) |
| **Oncorhynchus mykiss** | Dam | Built 1959 | 22 | 0.05 | 0.06 | Deiner m fl. (2007) |
| **Salmo trutta (stationary)** | Waterfall | waterfall + 12 km | 5 | 0.41 | 0.538 | J. Carlsson (2000) |
| **Salmo trutta (Stationary)** | Waterfall | waterfall + 2 km | 5 | 0.05 | 0.018 | J. Carlsson (2000) |
| **Salmo trutta** | | | | 0.25 | 0.176 | J Östergren (2006) |
| **Salmo trutta (migrating)** | Waterfall | Songstupet + 15 km | 10 | 0.06 | 0.09 | Dannewitz et al. (2014) |
| **Salmo trutta (migrating)** | Waterfall | Songstupet + 15 km | 10 | 0.19 | 0.13 | Dannewitz et al. (2014) |
| **Salvelinus fontinalis** | Waterfall | 61 m waterfall | 8 | 0.23 | 0.35 | Timm et al. (2015) |
| **Salvelinus fontinalis** | Waterfall | 4 m waterfall | 8 | 0.22 | 0.15 | Timm et at. (2015) |