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Upstream fish migration in relation to barriers in Fyrisån


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Abstract

Migration of fresh water fish are widespread and can be classified into three types: spawning, feeding and predator avoiding. Abiotic factors as temperature, light and water level influence the migration and the migration can be short diel movements within the same water system or long distance movements between different habitats. This study was performed to investigate temporal changes in upstream migration of fish in Fyrisån in relation to temperature, light availability and water level. Migration patterns were studied from early April to early June using a fyke net and a fish counter. Temperature and water level were recorded. Recordings from the fish counter showed that migration toccured mainly day time. A clear connection between migration patterns and environmental factors was observed. At higher temperature and decreasing water level the upstream migration increased. The fish species caught in the fyke net during the study were roach (*Rutilus rutilus*), perch (*Perca fluviatilis*), bleak (*Alburnus alburnus*), common bream (*Abramis brama*), eel (*Anguilla anguilla*), tench (*Tinca tinca*), ruffe (*Gymnocephalus cernua*) and white bream (*Abramis bjoerkna*). Three fish species; roach, perch and bleak, were observed ready to spawn. Migrating fish was also observed in the fish counter but pike (*Esox lucius*) was the only species that certainly could be identified when analyzing the silhoutte pictures.

Contents

1. Introduction

Organisms migrate for many reasons, over long and short distances and in many different ways such as flying, swimming, walking or drifting. Especially migration occurs between feeding and breeding areas and it may have a strong influence on the population dynamics and affect species composition (Brönmark *et al.*, 2008; Dingle & Drake, 2007).

Fish migration is influenced by environmental and developmental factors (Brodersen *et al.*, 2008; Gross, 1987; Jennings, 1996). The migration can be long distance movements between different water systems, such as the migration by salmonid species (Dodson, 1997) or short diel movements within a lake between the pelagic and littoral zones, which is typical for juvenile fish of many species for feeding and hiding from predators (Bohl, 1980; Eklöv, 1997).

Migration among freshwater fish is widespread (Lilja, 2003) but most studies of fish migration have been performed on economical important species such as salmonids. Therefore studies of fish migration between marine and freshwater environments (anadromous species) are more common than studies concerning fish migration within fresh water systems only (potamodromous species). Knowledge about migration of fresh water fish species has increased the latest decade (Brönmark *et al.*, 2008, Jungwirth *et al.*, 1998; Lucas & Barras, 2001). Recent studies have found that roach can migrate several kilometers to spawn (Baade & Fredrich, 1998) and pike have been reported to migrate several kilometers in just a few hours (Miller *et al.*, 2001).

Fish migration activities are influenced by abiotic factors such as variations in water temperature, water level and light availability (Hladik & Kubečka, 2003; Hohausová *et al.*, 2003; Lilja *et al.*, 2003; Worthington *et al.*, 1982). The migration is usually classified into three categories; spawning, feeding and refuge seeking migrations (Lucas & Barras, 2001; Meixler, 2009). Spawning activity plays a central role in fish migration and is often related to temperature which is an important regulating factor especially for the spring spawning migration. Mature fish return to natal streams to spawn synchronously when other mature fish are present, so called homing behaviour. Synchronized migrations are vital for maximizing reproductive success (Leggett, 1977). Spring spawning migration is known in some of the common freshwater fishes like pike (*Esox lucius*) (Vehanen et. al, 2006), roach (*Rutilus rutilus*) (Vøllestad & L'Abée-Lund, 1987), perch (*Perca fluviatilis*) (Berglund, 1978), ruffe (*Gymnocephalus cernus*), asp (*Aspius aspius*), common bream (*Abramis brama*) and bleak (*Alburnus alburnus*) (Hladik & Kubečka, 2003). Temperature also affects the length and intensity of spawning activity (Hladik & Kubečka, 2003; Vøllestad & L'Abée-Lund, 1987). The distribution of homing behaviour in fish species varies. Roach has been observed to have a homing precision as high as 92 % in a tributary to a lake in Norway (L'Abée-Lund & Vøllestad, 1985). A large part of a migrating pike population in lake Oulujärvi, in Finland, was observed to exhibit homing behavior as most of the pikes returned to the same spawning area in the following year (Vehanen *et al.*, 2006).

Seasonal changes in predation pressure and growth rate are also influenced by temperature. Predation is a strong mortality factor for fish (Romare & Hansson, 2003) and the major driving force of migration especially for smaller species and juvenile fish. In order to reduce the ratio between predation mortality and growth rate prey fish migrate to refuges areas in rivers (Brönmark *et al.*, 2008; Jepsen & Berg, 2002). Such changes in habitat use may involve a trade-off between predator avoidance and foraging. If the access to food is high the forager may accept the higher risk of predation or migrate to an area that gives better protection from predators but low access to food (Borcherding, 2002; Brönmark *et al.*, 2008; Hall *et al.*, 1979). Migration is energy costing and some fish may not have enough energy reserves to migrate (Brodersen *et al.*, 2008). At low temperatures fish decrease swim activity in order to reduce energy costs. For roach lower temperature threshold for feeding is around 15 C° (van Dijk *et al.*, 2001).

In unstable environments with fluctuating temperatures light inducement is important for spawning migration. In the spring the photoperiods become longer. The principal factor that induces spawning migration in roach is an increase in photoperiod (Vøllestad & L'Abée-Lund, 1987).

Species have different diel migration patterns. Some species migrate mainly daytime and other species during the night. Even within the same species small and large specimens can have different patterns of diel migration (Clark 1950; Franklin & Smith, 1963). Preyfish such as bleak and roach was found out by Hohausová *et al*. (2003) to mainly migrate between dusk and dawn and perch to migrate throughout most of the day. Another study has however demonstrated that roach mainly migrate during daytime (Baade & Fredrich, 1998). Pike are, according to Casselman (1996), active mainly daytime but usually forage at dusk.

When the snow is melting in the spring water flow and water level become higher. Changes in water levels may function as an initiating factor for migration. High water flow may help the fish to find the entrance to the stream but if flows are very high they can instead be a hinder for fish migration (Hohausová *et al*., 2003; Jonsson, 1991). Very high water flows can also lead to displacements of fish eggs and larvae (Mann, 1997).

For migrating fish species it is important for the survival that they can move freely between feeding and spawning areas. Many fish species cannot complete their life cycles in the lake environment and need access to river habitats (Hladik & Kubečka, 2003). Worldwide rivers are among the most heavily exploited water ecosystems (Dynesius & Nilsson, 1994; Malmquist & Rundle, 2002). Different types of barriers, natural and artificial, can prevent fish to migrate between habitats which can lead to injury of fish, decline or even extinction of populations (Meixler *et al*., 2009). Manmade barriers have lead to fragmentation especially of running water systems. In Sweden there are only four large rivers that are not exploited for electricity production from hydro power. In many water systems different methods are used to overcome these problems. Obstructions like fish ladders, fish elevators and channel bypasses have been built to facilitate migration of fish such as cyprinids, esocids and percids (Ovidio & Philippart, 2002).

1.1 Aims of the study

The main aim of the study was to investigate temporal changes in migration of fish in Fyrisån in relation to temperature and water level. The test for temporal changes in migration was conducted at two levels: continuously by the use of a camera that automatically registered fish passing the ladder and manual net catch that was checked almost daily. Another aim was to assess migration patterns for different species and if possible estimate the frequency of fish ready to spawn. The study also observed if there were patterns in diel migration.

Earlier investigations of fish in Fyrisån have only been performed during autumn. This study observed spring migration in the river from early April to early June.

2. Method

2.1 Study area

The present study was carried out in River Fyrisån (coordinates X 1602920; Y 6638703, RT90) that is located in Uppsala County. From the 8th of April to the 2nd of June a fyke net was placed at Kvarnfallet to investigate upstream migration in the river. From the 20th of April to the 2nd of June a fish counter at Islandsfallet located downstream Kvarnfallet was used to investigate upstream migration in the river (Appendix).

The catchment area of River Fyrisån is approximately 2000 km^2 and covers almost one third of Uppsala County. This area consists of 59% forest, 5 % wetland, 32 % agricultural land, 2 % water surface and 2 % other land. The total length of the river is approximately 80 km (Brunberg & Blomqvist, 1998). The width of the river between Kvarnfallet and Islandsfallet varies between 12-31 m and the mean water flow in Fyrisån over the whole year is 14 m^3 s^{-1}. The water level is measured continuously by a water meter in Fyrisån. The water meter is placed upstream Islandsfallet where the water depth normally is about 0,5 m. The water depth varies and is at some places more than 3 meters (pers. com. Anders Larsson; Persson *et al.*, 2009).

Fyrisån is highly affected by the agricultural landscape (82 Tot- P µg/l) and has significantly colored water and very good buffer capacity (pH 7.6). Its outlet from Lake Dannemorasjön is in the central part of Uppsala County and the river flows out in Lake Ekoln, south of Uppsala. Fyrisån has several tributaries; Vattholmaån, Vendelån, Björklingeån and Jumkilsån which flows into Fyrisån upstream Uppsala and Sävjaån flows into Fyrisån downstream Uppsala. (Brunberg & Blomqvist, 1998) Fyrisån represents a substantial part in the community development of Uppsala County. It is used as a water source, recipient, transport corridor and is overall an important element in the city of Uppsala (Brunberg & Blomqvist, 1998).

The dominating bottom substrate in Fyrisån at the study area is a stony gravel bottom partly mixed with clay. The stones are in sizes of 5-30 cm (Persson et. al, 2009). In the fish pass way at Kvarnfallet the vegetation is abundant with species as yellow water lily (*Nuphar luthea*), common club-rush (*Schoenoplectus lacustris*), bur-reed (*Sparganium* sp.), sedge (*Carex* sp.), common reed (*Phragmites australis*) and pond-weed (*Potamogeton* sp.). Downstream Kvarnfallet the vegetation consists of small stocks of yellow water lily, common club-rush, pond-weed and bur-reed. The density of vegetation increases downstream. Suitable spawning areas are situated downstream Kvarnfallet and Ulva Kvarn (Berglund, 2005).

Fyrisån has several barriers. At two of these barriers fish ladders have been built. One ladder is situated at Kvarnfallet and the other one is situated at Islandsfallet, both down town Uppsala (Appendix). The fish ladder situated at Kvarnfallet was opened in April 2007 and the ladder at Islandsfallet was opened in April 2008. Before the ladders were built all upstream migration was prevented since 1841 when Islandsfallet was constructed. The fish ladders were built to facilitate spawning migration of the endangered species asp (*Aspius aspius*) but probably many other fish species will also benefit from the ladders. At earlier fish inventories with electro fishing and seine fishing, 15 different fish species have been observed. These inventories have been performed during the autumn since 2005 downstream Ulva Kvarn and downstream Kvarnfallet.

The construction of the fish ladder at Islandsfallet consists of a 40 m long channel with 14 small basins. The openings between the basins are 28 cm^2. The water speed is slowed down by a screen placed in each of the 14 basins. The fish counter was placed at the end of the ladder upstream the barrier. The fish pass way at Kvarnfallet is composed of a combination of a baffle fish way and a channel. A baffle fish way consists of lamellas in which the water flows through, creating turbulence in the water. The fish can then swim along the bottom in the reduced water flow (pers. com. Anders Larsson).

2.2 Field study

2.2.1 Fyke net

A fyke net was used to catch all the fish migrating upstream (Fig. 1). The net was 7.5 m long with a height of 0.65 m and a 5 m wide opening. The mesh size of the net was 20 mm. On each side of the opening a net was attached with a length of 4 m. All migrating fish were forced to swim into the net in order to continue further upstream, thus the net captured all migrating fish. The fyke net was placed at Kvarnfallet in the fish pass way between the baffle fish way and the channel with the net opening faced downstream. The net was secured to the bottom using wooden sticks and stones. A narrow and shallow location was chosen, 4 m wide and 0.7 m deep, to easily block the whole stream with the fyke net. The use of a fyke net made it possible to do accurate determination of species and observe if there were fish ready to spawn.

The fyke net was emptied weekdays from 8th April to 16th of May. From the 17th of May to 2nd of June the net was emptied every day. The fish caught in the net were placed in a bucket with fresh water, counted, determined of species, length measured and if possible spawning status was determined. The spawning status of the fish was estimated by observing eggs or sperm by pressing the abdomen. The fish was then released upstream the fyke net. In order to minimize the exposure to stress the measurements made outside the water environment was done as fast as possible. Only 2 fish out of 164 died during the investigation. The water temperature was also measured each day during investigation. Temperature was measured close to the fyke net 10 cm below the water surface.

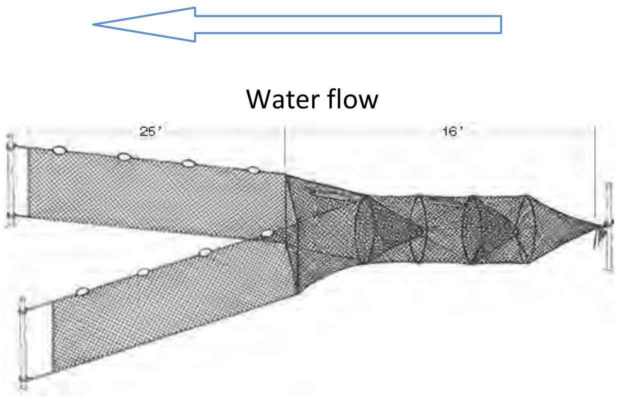


Figure 1.The fyke net used in the study was 7,5 m long, with a height of 0,65 m and a 5 m wide opening. Two nets were attached to each side of the opening with a length of 5 m.

2.2.2 Fish counter

On the 20th of April a fish counter was installed in River Fyrisån at Islandsfallet. The counter consists of a slide box and two scan plates with IR-transmitters (Fig. 2). A small current is passed between the plates and the presence of an object changes the current recording its length, height and weight. A silhouette picture is also created and time of the passing objects is registered. These data were stored in a data unit. All fish migrating upstream in the counter between 21th of April to 2nd of June were used in the study.

A B

Figure 2. The slide box where the two scan plates are placed (A). One of two scan plates with IR-transmitters (B).

2.3 Statistical analyses

Statistical analyzes were done using Excel, Minitab and SPSS softwares. The relation between temperature and the frequency of fish passing the fyke net and the fish counter was analyzed using linear regression. A linear regression was also used for testing the relationship between frequency of fish and water level. Data were lnx+1 transformed to achieve normal distribution.

Patterns in diel migration was analyzed using General linear model and ANCOVA. The day was divided into four periods: sunrise around 4 am to 7 am, day time around 7 am to 8 pm, sunset around 8 pm to 10 pm and night around 10 pm to 4 am. These divisions were done based on earlier studies of diel patterns (Hohausová *et al.*, 2003; Skov *et al.*, 2008).

3. Results

3.1 Abiotic factors and fish migration

The temperature fluctuated between 3.2 C° and 18.3 C° during the study period (8th of April to the 2nd of June). The first fish caught in the fyke net were two roach on the 8th of April when temperature was 3.2 C°. However the main upstream migration started the 28th of April both in the fyke net and the fish counter when the temperature was 9.1 C° (Fig. 3a). Two peaks of upstream migration of fish was observed that almost coincided in the fyke net and the fish counter. The first peak of migrating fish in the fish counter was the 16th of May when the temperature was 16 C°. The second peak in the fish counter was on the 21st of May when the temperature was 18.3 C°. On the 18th of May when the temperature was 16.7 C° there was a first peak of migrating fish in the fyke net. On the 23rd of May there was a second peak in the fyke net when the temperature was 17,1 C°.

2009-2010 was a long and snowrich winter with a late snowmelt. The water level raised to a level about 1 m which totally covered the fish ladders with water possibly hindering the fish to pass the barriers. A high water level also imply a higher water flow. The first day when migrating fish were observed the 28th of April the water level was 0,8 m deep and there was no overflow of water at the edges of the fish ladder at Islandsfallet. The water level continued to decrease to approx. 0.4 m and during the rest of the study the water level remained almost the same with small fluctuations (Fig. 3b). Registration from previous years shows that there are considerable differences and fluctuations in the water level. No calculations are published about the average water level but a review of the data for the last ten years shows that water levels for spring 2010 can be regarded as very high. During the latest decade water levels above 1 m have not been recorded.

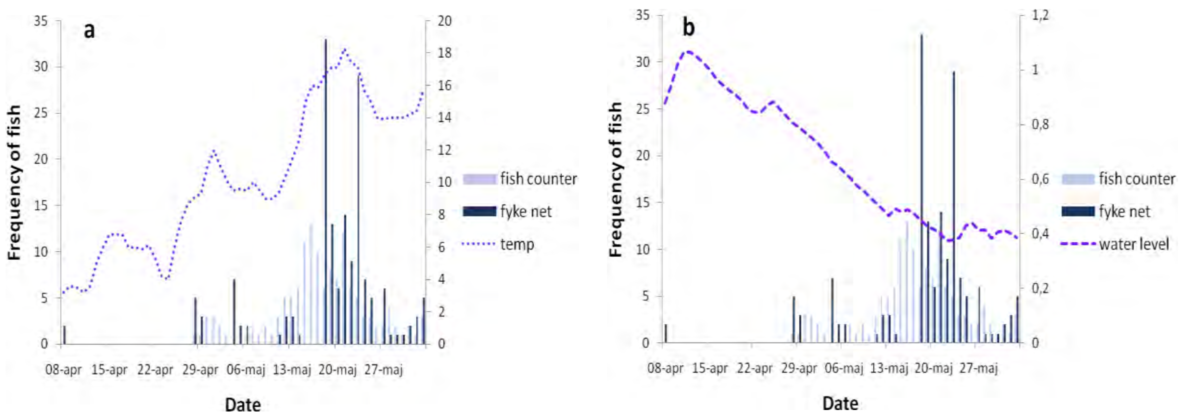


Figure 3. The frequency of fish caught in the fyke net during the study from the 8th of April to the 2nd of June and the frequency of fish recorded in the fish counter from the 21st of April to the 2nd of June. The water temperature (a) and water level (b) during the period is displayed.

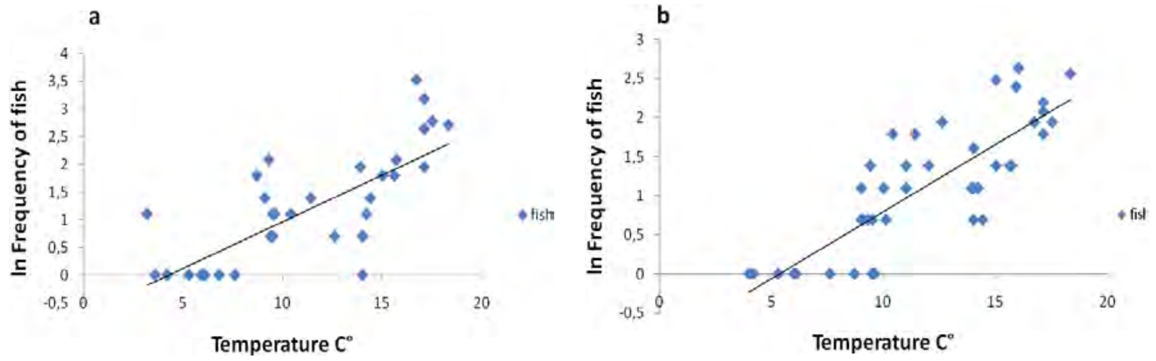


Figure 4. Linear regression between frequency of fish and temperature in the fyke net (a) and the fish counter (b). Y-axis is ln (number of fish) +1.

The amount of migrating fish in the fyke net increased significantly with temperature. About 56 % of the observed variation in number of individuals can be explaned by increasing temperature. R^2=0,56, P<0,0001 (Fig. 4a). In the fish counter about 66 % of the observed variation in number of individuals can be explaned by a variation in temperature. R^2= 0,66, P <0,0001 (Fig. 4b).

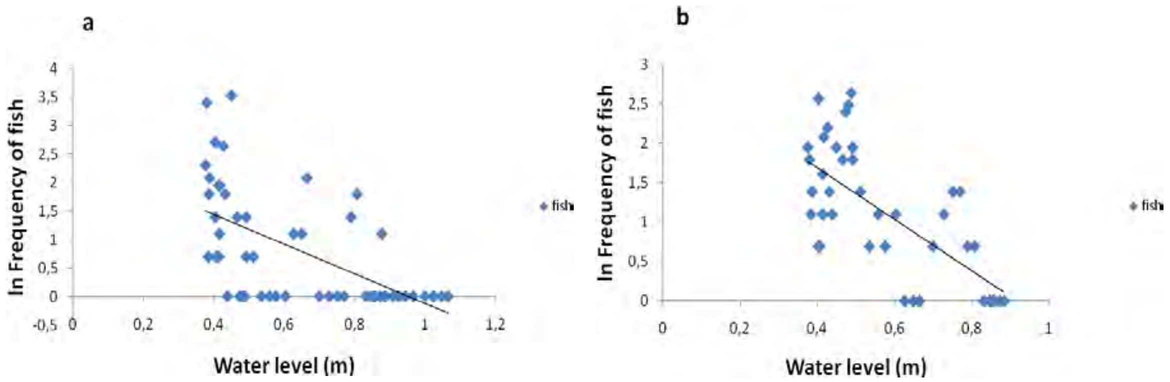


Figure 5. Linear regression between frequency of fish and the water level in the fyke net (a) and the fish counter (b). Y-axis is ln (number of fish) +1.

The amount of fish significantly increased with a decrease in water level in the fyke net. About 37 % of the observed variation in number of individuals can be explaned by changes in water level. R^2 = 0,37, P<0,0001 (Fig. 5a). In the fish counter about 49 % of the observed variation in number of individuals can be explained by a change in water level. R^2= 0,49, P <0,0001 (Fig. 5b).

3.2 Fyke net catches

A total number of 164 fish were caught in the fyke net during the study from the 8th of April to the 2nd of June (Fig. 6a). Eight different fish species were identified. The species and number of individuals were; roach 105, perch 33, bleak 17, common bream 5, white bream 1 (*Abramis bjoerkna*), ruffe 1 (*Gymnocephalus cernua*), eel 1 (*Anguilla anguilla*) and tench 1 (*Tinca tinca*). The dominating fish species in the catches was roach. Two individuals of roach were caught on the 8th of April and then no more fish were caught until the 28th of April. The net was only emptied during weekdays from 8th of April to 16th of May why some gaps exist in the graphs. Due to the increasing amount of migrating fish from 18th of May the net was emptied every day until the 2nd of June. The maximum catch was recorded on 18th of May when 33 fish were caught. The species were 26 roach, 5 perch, 1 bleak and 1 common bream. The second largest catch was the 23rd of May when 29 fish were caught. The catch consisted of 11 roach, 5 perch and 7 bleak. Otherwise the frequency of caught fish varied between 0-14 (Fig. 6a).

The dominating size of the fish caught during the study was between 150-200 mm (82 individuals). 46 fish caught were shorter than 150 mm and 33 fish longer than 300 mm. Roach was found in all three size classes. Perch was found in the two larger size classes. Bleak and the only ruffe caught were found in the smallest size class. Common bream, white bream, eel and tench were found in the largest size class (Fig. 6b).

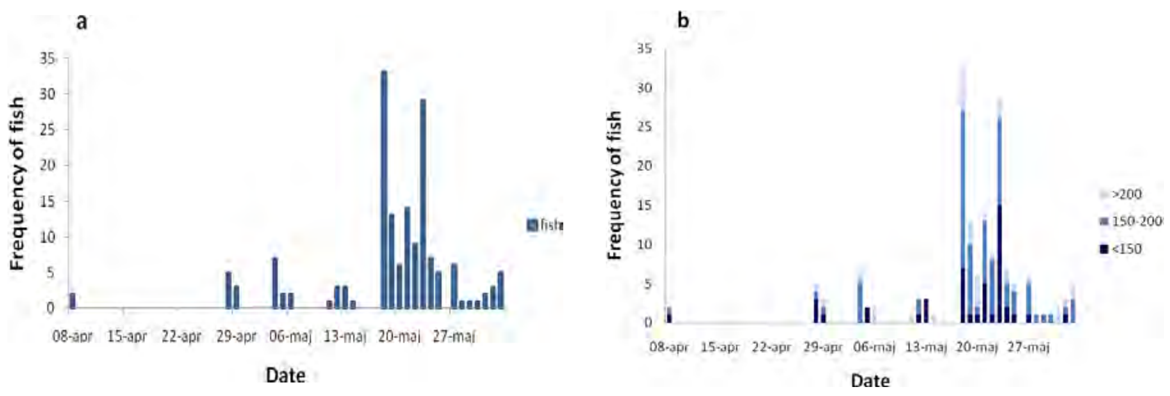


Figure 6. The total number of fish caught in the fyke net (n=164) during the study from the 8th of April to the 2nd of June (a) and distribution of fish sizes in the fyke net, divided into 3 size classes. Fish shorter than 150 mm, 150-200 mm and longer than 200 mm (b).

The three most abundant species in the fyke net catches were roach, perch and bleak. Fish ready to spawn were observed among all three species and the first observed spawning fish was a female perch on 29th of April. On 4th of May several spawning males of roach were observed. The first observed spawning bleak was females on 23th of May.

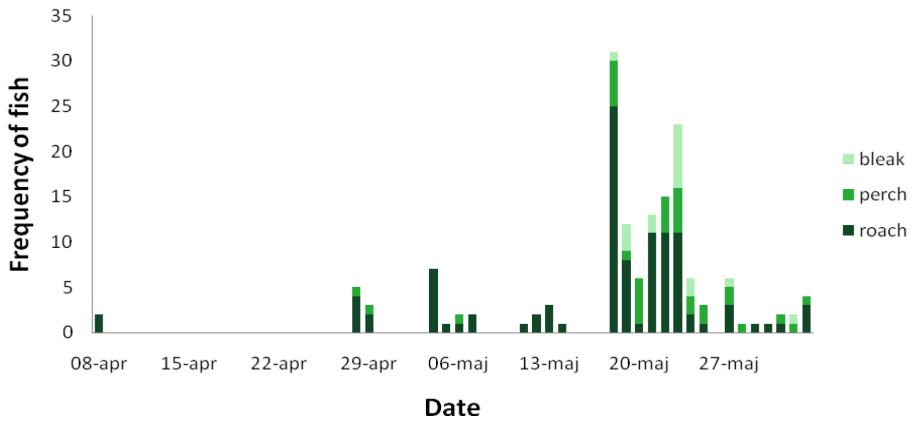
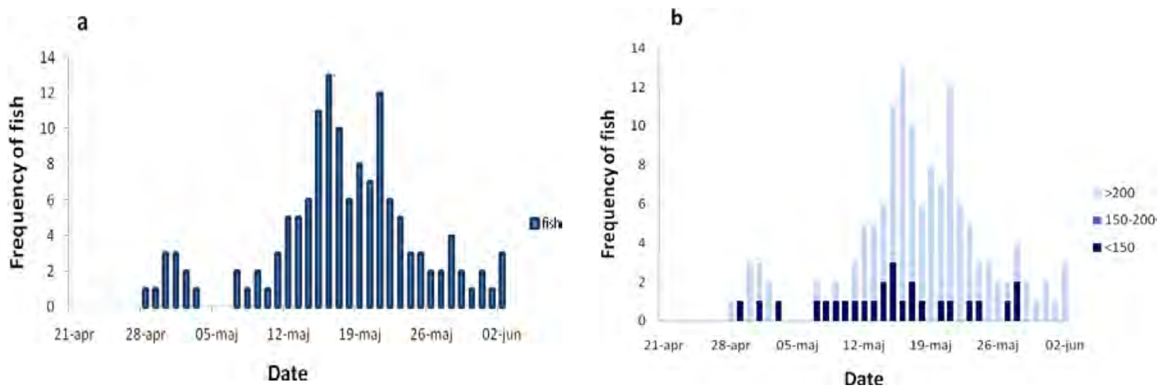


Figure 7. Frequency of roach, perch and bleak caught in the fyke net during the study from the 8th April to the 2nd of June. 105 roach, 33 perch and 17 bleak were caught.

3.3 Fish counter recordings

A total number of 137 migrating fish were registered during the study from the 21st of April to the 2nd of June (Fig. 8a). Pike was the only species that for certain could be identified when analyzing the silhoutte pictures. More uncertain analyzes of the pictures indicates passes of smaller fish of common bream, different cyprinids and eel. It is not certain that all of these are fish, it could also be drifting debris. However, in the middle of May the frequency of observations increased. The two days when most of the fish passed the counter were the 16th of May and the 21th May when 13 and 12 passing fish were registered respectively. During the other time the amount of passing fish varied between 0-14.



Figur 8. The total number (a) and size distribution (b) of fish registered in the fish counter (n=137) during the period from 21st of April to 2nd of June. Distribution of fish sizes in the fish counter are divided into 3 size classes, fish smaller than 150 mm, 150-200 mm and larger than 200 mm.

The dominating fish size passing the counter upstream were fish longer than 200 mm with a total number of 111 specimens. No fish in the size class between 150-200 were registered. 26 fish shorter than 150 mm were registered (Fig. 8b). An observation of a video film showed an intense upstream movement of fish, certainly shorter than 200 mm, in the counter.

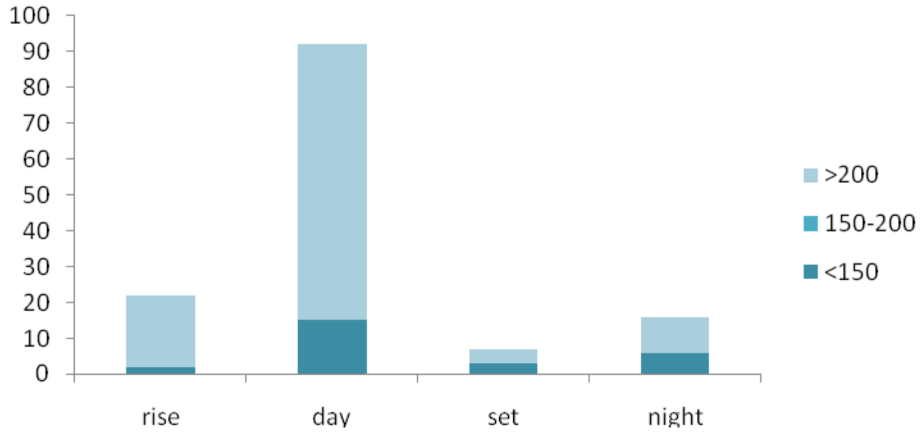


Figure 9. Diel distribution of fish migration in the fish counter from the 21st of April to the 2nd of June. Sunrise hours: 4.00 am – 7.00 am, day hours: 7.00 am – 20.00 pm, sunset hours: 20.00 pm - 22.00 pm, night hours: 22.00 pm – 4.00 am.

Migration activity was significantly greater daytime than at any other time (Fig. 9, ANOVA, $F_{3,132}$ = 6,090, P<0,001), and there was no significant difference in migration among the other time periods (P>0.7). Furthermore there was a significant difference in migration between different sizes of fish where larger fish seemed to migrate more frequently ($F_{3,132}$ =162,283, P<0,001), but there was no interaction between migration and time ($F_{3,132}$ = 0,628, P>0,001)

4. Discussion

My results show a strong upstream migration in River Fyrisån where several different species migrated upstream the river during the spring of 2010. The migration was probably mainly related to spawning where three species were observed ready to spawn and the migration pattern changed at changes in water temperature and water level. At higher temperatures and falling water levels in Fyrisån the migration increased. These results are similar to the observations by Vøllestad & L' Abée-Lund (1987) on upstream migration of roach in Vollebekken, a small tributary to Lake Årungen in Norway, situated at the same latitude as river Fyrisån. Migration was observed by the fish counter in river Fyrisån to occur mainly daytime. Baade & Fredrich (1998) observed roach to migrate mainly daytime. However other studies have observed migration of cyprinid fish to occur during night. During the study period roach was caught almost every time the fyke net was emptied and the migration of roach peaked during the observation time.

Temperature is an important factor for initiating spawning migration but temperature sensivity differs between species (Hladik & Kubečka, 2003; Hohausova *et al*., 2003; Lilja *et al*., 2003). In River Fyrisån different fish species were observed to start their spawning migration at different temperatures. Pike is often the species that starts their spawning at lowest temperatures in the spring. In Lake Erie, Ohio migration of spawning pikes were observed when the water temperature was 0 C° (Clark, 1950). A study performed by Vehanen *et al.* (2006) observed that a great part of a population of pike migrated upstream a river for spawning when the water temperature was around 4 C°. Because no pike were caught in the fyke net it is not possible to determine if there were any pike ready to spawn. As the first pike was recorded in river Fyrisån when the temperature was as high as 9 C° it is unlikely that the movement of pike was related to spawning migration. The recordings of a rather large number of pikes - many of them larger than 500 mm - during the study indicates that migration occurs in the river for other reasons than spawning migration. Vehanen *et al.* (2006) observed that some pikes made migrations during the whole year within the river system.

Perch ready to spawn was observed in the fyke net. Berglund (1978) observed a start of spawning migration of perch when the water temperature was about 10 C° in River Ängerån. According to Hladik & Kubečka (2003) spawning migration for perch was observed at temperatures between 8-12 C°.This is consistent with my findings of the start of migrating perch. The majority of perch in River Fyrisån (approx. 80%) was caught when the temperature was between 14 C° and 18 C° and most of them were larger than 200 mm why it is likely that they were ready to spawn (Heibo & Magnhagen, 2005). Hokanson (1977) observed spawning migration of perch at a wide temperature span between 5-18 C°.

Upstream migration of roach started the same day as perch in River Fyrisån. Roach ready to spawn was however observed a few days later than perch ready to spawn. It is likely to believe that several of the roach caught were ready to spawn because the temperature was in the preferred range for spawning and that most fish were larger than 150 mm. Several studies have observed spawning migration patterns of roach. During three springs in Vollebekken spawning migration of roach was observed. The migration started in mid- May each year with water temperatures varying between 6-10 C°. The spawning migration lasted between 15-25 days dependent on variations in temperature. In years with rapid increase in temperature the spawning period was more synchronized. In years with low or slowly increasing temperatures the spawning period was longer (Vøllestad & L' Abée-Lund, 1987). Hladik & Kubečka (2003) observed, in the tributary Římov of River Malše in the Czech Republic, that the main spawning migration of roach started at the turn of April and May when temperatures reached 13-14 C° and lasted for a few days. The start of spawning migration of roach in River Fyrisån is consistent with the study in Vollebekken regarding temperature and with the study in Římov regarding date. This indicates that temperature is more important than date for the start of spawning migration of roach. According to Vøllestad & L' Abée-Lund (1987) the low temperatures of migration of spawning roach can be an adaptation to more northern latitudes. A peak of roach caught in the fyke net occurred during a rather short time period from the 18th to the 23rd of May. The peak of roach caught in the fyke net can maybe have started earlier but the net was not in use from the 14th to the 17th of May. During this short time period there was an increase in temperature of 4 C°. The maximum of this peak can have occurred during these days. As the fish counter did not mainly record fish smaller than 200 mm and it was great difficulties to identify different species it is unfortunately not possible to say anything for sure about the duration and maximum of this peak.

Bleak was first observed in the end of May but it is likely that the bleak could swim through the meshes of the fyke net because the bleak was stuck into the meshes and the bleak is also too small to be recorded by the fish counter. The start and the duration of the spawning migration is therefore uncertain. The bleak was caught during the second half of May but with obvious differences in number between different days. The first bleak was observed when the temperature was 16.7 C°. Hladik & Kubečka (2003) observed an intense spawning migration of bleak when temperatures reached 13-14 C° and it lasted more than a month.

At higher temperatures and decreasing water level the upstream migration increased. The highest activity during the study lasted approximately one week when the temperature was over 15 C°. When the temperature after this period dropped below 15 C° at the 26th of May, because of heavy rainfall, there was a clear decrease in the number of migrating fish appearing both in the fyke net and the fish counter. However, it is not clear whether the decreasing migration is dependent on temperature. Another explanation to the lower activity could be that the spawning migration was completed. The study was finished before the water temperature again raised to 15 C° making it difficult to say whether there was another subsequent peak in spawning migration. According to studies on spring spawning migration on roach performed by Vøllestad & L' Abee-Lund (1987) and Hohausova et. al (2003) the migration is normally completed in late May. Therefore the observed peak in spawning migration was likely the only one in Fyrisån in spring 2010. In a study performed in the stream Äijälänsalmi, Finland, the migration peaked when the temperature was only 10 C° (Lilja *et al*., 2003), a temperature significantly lower than in river Fyrisån, suggesting that a peak in spawning migration can vary not only with temperature but also with latitude.

At northern latitudes the elevation in temperature in spring causes thawing, resulting in increased water discharge with higher water levels in rivers and flooding of surrounding lowland areas (Lucas &Barras, 2001). Water level changes have been shown in many studies to be an important factor for initiating spawning migration (Northcote, 1984; Clark, 1950). Many species start their migration when the spring peak has passed. In Vollebekken migration of roach were initiated with decreasing water levels. High flows may act as a hinder for migration (Jonsson, 1991). At a water level of 0,8 m in river Fyrisån there was no overflow in the fish ladder which probably was important for the start of migration.

The two roach caught in the beginning of April could possibly have stayed in Fyrisån during winter. Several fish caught in the fyke net in River Fyrisån were small and probably not ready to spawn. Skov *et al*. (2008) observed that roach and white bream in Lake Krankesjön migrated into streams during winter and stayed there until spring probably to avoid predation. In Lake Stigsholm, Denmark, Jepsen & Berg (2002) found the same pattern with roach exposed to predation. It is possible that some fish use river Fyrisån as refuge area to avoid predation. Such habitat changes may involve a trade-off between avoiding predation and foraging because the supply of food is often higher in lakes, but the risk of being predated is often lower in rivers (Brönmark *et al*., 2008).

Patterns of diel migration can also be a strategy to avoid predation. Different studies have shown that fish species exhibit diel patterns in their migration. Fish sensitive for predation has been found to migrate mainly at night or around dusk and dawn (Bohl 1980; Skov et. al 2008). In river Fyrisån the recorded fish in the counter migrated mainly daytime between 8.00-19.00. It is likely that the pattern of diel migration had been different if the fish counter would have recorded all fish. It is however a clear pattern that large fish migrate during daytime. Skov et. al (2008) observed roach, white bream and rudd to migrate generally in the morning or early evening. Lilja et. al (2003) observed that migration of perch, common bream, ruffe and white bream mainly occured around dawn and dusk. Baade & Fredrich (1998) observed a different pattern with roach, mainly migrating daytime. Also observations in diel patterns of migration in pike differ (Diana et. al., 1998; Franklin & Smith, 1963). Probably there is no general pattern of diel migration.

The number of recorded fish in the fish counter with sizes less than 200 mm was quite small (approx 20 %) while the majority (approx. 80 %) of fish caught in the fyke net were smaller than 200 mm. It is likely that the fish counter shows a biased picture of fish migration in Fyrisån. For example, a video film made at one occasion at the fish counter showed an intense stream of migrating fish certainly shorter than 200 mm. None of these were registered in the fish counter. Fish counters have been extensively used for recording adult salmonid (Lucas & Barras, 2000). In river Placentia, Canada, accuracy and reliability of a fish counter was tested on adult Atlantic salmon (*Salmo salar*). In the study a trap with 517 Atlantic salmon was released downstream the fish counter to see how many fish the fish counter recorded. The number of fish observed in the fish counter was 517 demonstrating the high accuracy for large fish (Reddin *et al*., 1992). Dunkley & Shearer (1981) used a fish counter 1977 and 1978 to observe migration of adult salmon in river North Esk. Also a video camera was used to investigate the reliability of the fish counter. For fish larger than 500 mm the compliance between what the fish counter recorded and fish filmed were much higher than for fish smaller than 500 mm. Fish counters are useful for counting large fish. According to Lucas & Barras (2000) fish counters with electrodes exhibit a poor efficiency in detecting fish smaller than 250 mm and also in detecting fish that swim in shoals.

To observe migration of large fish the use of a fish counter is a good method. It is less time demanding than the use of a fyke net and the exact time when the fish migrate is given. The use of a fyke net is however a better method for estimating which species that migrate and observe fish ready to spawn.

4.1 Concluding remarks

Understanding the underlying factors for fish migration is challenging. My findings clearly show a connection between migration patterns and environmental factors. It is however difficult to say to what extent environmental factors affect the migration. No evaluation regarding the influence of light was possible to do because this study only included one spring migration. It would be interesting to study spring spawning migration during several spring periods in Fyrisån to test if the migration patterns differ between years. It would also be of interest to place a fyke net adjacent to the fish counter at Islandsfallet to observe which species that pass and if it is different from which species that pass the fish pass way at Kvarnfallet.

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6. References

Anders Larsson: verbal reference

Baade U. & Fredrich F. (1998) Movement and pattern of activity of the roach in the river Spree, Germany, Journal of fish biology, **52**, 1165-1174

Berglund I. (1978) Spawning migration of the perch, *Perca fluviatilis* L., in a subarctic Swedish coastal stream, Aquilo Series Zoologica, **18**, 43-48

Berglund J. (2005) Aspens leklokaler i Uppsala län rapport 2005/2

Bohl E. (1980) Diel pattern of pelagic distribution and feeding in planktivorous fish, Oceologia, **44**, 368-375

Borcherding J., Bauerfeld M., Hintzen D. & Neumann D. (2002) Lateral migrations of fishes between floodplain lakes and their drainage channels at the Lower Rhine: diel and seasonal aspects, Journal of fish biology, **61**, 1154-1170

Brodersen J., Nilsson P. A., Hansson L-A., Skov C., Brönmark C., (2008) Condition-dependent individual decision-making determines cyprinid partial migration, Ecology, **89**, 1195-1200

Brodersen J., Ådahl E., Brönmark C. & Hansson L-A. (2008) Ecosystem effects of partial fish migration in lakes, Oikis, **117**, 40-48

Brunberg A-K. & Blomqvist P. (1998) Vatten i Uppsala län 1997. Rapport nr 8/1998

Brönmark C., Skov C., Brodersen J., Nilsson P. A. & Hansson L. A. (2008) Seasonal migration determined by a trade-off between predator avoidance and growth, **3**,

Casselman J. M. (1996) Age, growth and environmental requirements of pike In: Craig, J.F., ed. Pike: biology and exploitation, London: Chapman & Hall: 69–102.

Clark C. F. (1950) Observations on the spawning habitats of the northern pike, *Esox lucius*, in Northwestern Ohio, Copeia, **4**, 285-288

Craig J.F. (1987) *The biology of perch and related fish*. Croom Heln, London

Dingle H. & Drake A. (2007) What is migration?, Bioscience, **57**, 113-127

Dodson J. J., (1997) Fish migration: an evolutionary perspective

Dunkley D. A. & Shearer W. M. (1981) An assessment of the performance of a resistivity fish counter, Journal of fish biology, **20**, 717-737

Dynesius M. & Nilsson C. (1994) Fragmentation and flow regulation of river systems in the Northern Third of the World, Science, **266**, 753-762

Eköv P. (1997) Effects of habitat complexity and prey abundance on the spatial and temporal distributions of perch (*Perca fluviatilis*) and pike (*Esox lucius*), **54**, 1520-1531

Franklin D. R & Smith Jr L. L (1963) Early life history of the northern pike (*Esox lucius*) with special reference to the factors influencing the numerical strength of year classes, Transactions of the American Fisheries Society, **92**, 91-110

Geeraerts C. (2007) Mobility of individual roach *Rutilus rutilus* (L.) in three weir-fragmented Belgian rivers, Hydrobiologia, **582**, 143-153

Gross M. R. Evolution of diadromy in fishes, American fisheries society symposium, **1**, 14-25

Hall D. J., Werner E. E., Gilliam J. F., Mittelbach G. G., Howard D., & Doner C. G. (1979) Diel foraging behavior and prey selection in the golden shiner (*Notemigonus chrysoleucas*), Journal of the fisheries research board if Canada, **36**, 1029-1039

Heibo E. & Magnhagen C. (2005) Variation in age and size at maturity in perch (*Perca fluviatilis* L.), compared across lakes with different predation risk, Ecology of freshwater fish, **14**, 344-351

Hladik H. & Kubečka J. (2003) Fish migration between a temperate reservoir and its main tributary, Hydrobiologia, **504**, 251-266

Hokanson K.E.F (1977) Temperature requirements of some percids and adaptations to the seasonal temperature cycle, J. Fish. Board Can, **34**, 1524-1550

Hohausová E., Copp G. H. & Jankovský P. (2003) Movement of fish between a river and its backwater: diel acticity and relation to environmental gradients, Ecology of Freshwater, **12**, 107-117

Holčik J. & Bastl I. (1976) Ecological effects of water level fluctuation upon fish populations in the Danube river floodplain in Czechoslovakia, Acta Scientarium Naturalium

Jennings M. J. & Philipp D. P (1996) Evidence for heritable preferences for spawning habitat between two walleye populations, Transactions of the American fisheries society, **125**, 978-982

Jepsen N. & Berg S. (2002) The use of winter refuges by roach tagged eith miniature radio transmitters, Hydrobiologia, **483**, 167-173

Jonsson N. (1991) Influence of water flow, water temperature and light on fish migration, Nordic Journal of Freshwater Research, **66**, 20-35

Kestemont P., Rinchard J., Feyes V. & Fostier A. (1999) Spawning migrations, sexual maturity and sex steroid levels in female roach *Rutilus rutilis* from the River Meuse, Aquatic science, **61**, 111-121

Kubecka J. & Duncan A. (1998) Diurnal changes of fish behaviour in a lowland river monitored by a dual-bem echosounder, Fisheries research, **35,** 55-63

L'Abée-Lund J. H. & Vøllestad L. A. (1985) Homing precision of roach *Rutilus rutilus* in Lake Årungen, Norway, Environmental biology of fishes, **13**, 235-239

Leggett W. C. (1977) The ecology of fish migration, Annual review of ecological systems, **8**, 285-308

Lilja J., Keskinen T., Marjomäki T. J., Valkeajärvi P. & Karjalainen J. (2003) Upstream migration activity of cyprinids and percids in a channel, monitored by a horizontal split-beam echosounder, Aqutaci Living resources, **16**, 185-190

Lucas M. C. & Barras E. (2000) Methods for studying spatial behaviour of freshwater fishes in the natural environment, Fish and fisheries, **1**, 283-316

Malmquist B. & Rundle S. (2002) Threats to the running water ecosystems of the world, Environmental conservation, **29**, 134-153

Mann R. H. K. & Bass A. B. (1997) The critical water velocities of larval roach (*Rutilus rutilus*) and dace (*Leuciscus leuciscus*) and implications for river management, Regulated rivers: research and management, **13**, 295-301

Meixler M. S., Bain M. B. & Walter T. W. (2009) Predicting barrier passage and habitat suitability for migratory fish species, 2782-2791

Miller L. M., Kallemeyn L. & Senanan W. (2001) Spawning-site and natal-site fidelity by northern pike in a large lake: mark-recapture and genetic evidence, Transactions of the American fisheries society, **130**, 307-316

Ovidio M. & Philippart J-C. (2002) The impact of small physical obstacles on upstream movements of six species of fish, Hydrobiologia, **483**, 55-69

Persson J., Loreth T. & Johansson G. (2010) Fiskinventering i Fyrisån 2009, Upplandsstiftelsen

Persson J., Loreth T. & Johansson G. (2009) Djupfördelning, bottensubstrat och undervattensvegetation i Årummet i Fyrisån, Upplandsstiftelsen

Reddin D. G., O'Connell M. F. & Dunkley D. A. (1992) Assessment of an automated fish counter in a Canadian river, Aquaculture Research, **23**, 113-121

Romare P. & Hansson L-A. (2003) A behavioural cascade: Top-predator induced behavioralshifts in planktivorous fish and zooplantlon, Limnol Oceanogr, **48**, 1956-1964

Skov C., Brodersen J., Nilson P. A., Hansson L-A. & Brönmark C (2008) Inter- and size specific patterns of fish seasonal migration between a shallow kale and its streams, Ecology of freshwater fish, **17**, 406-415

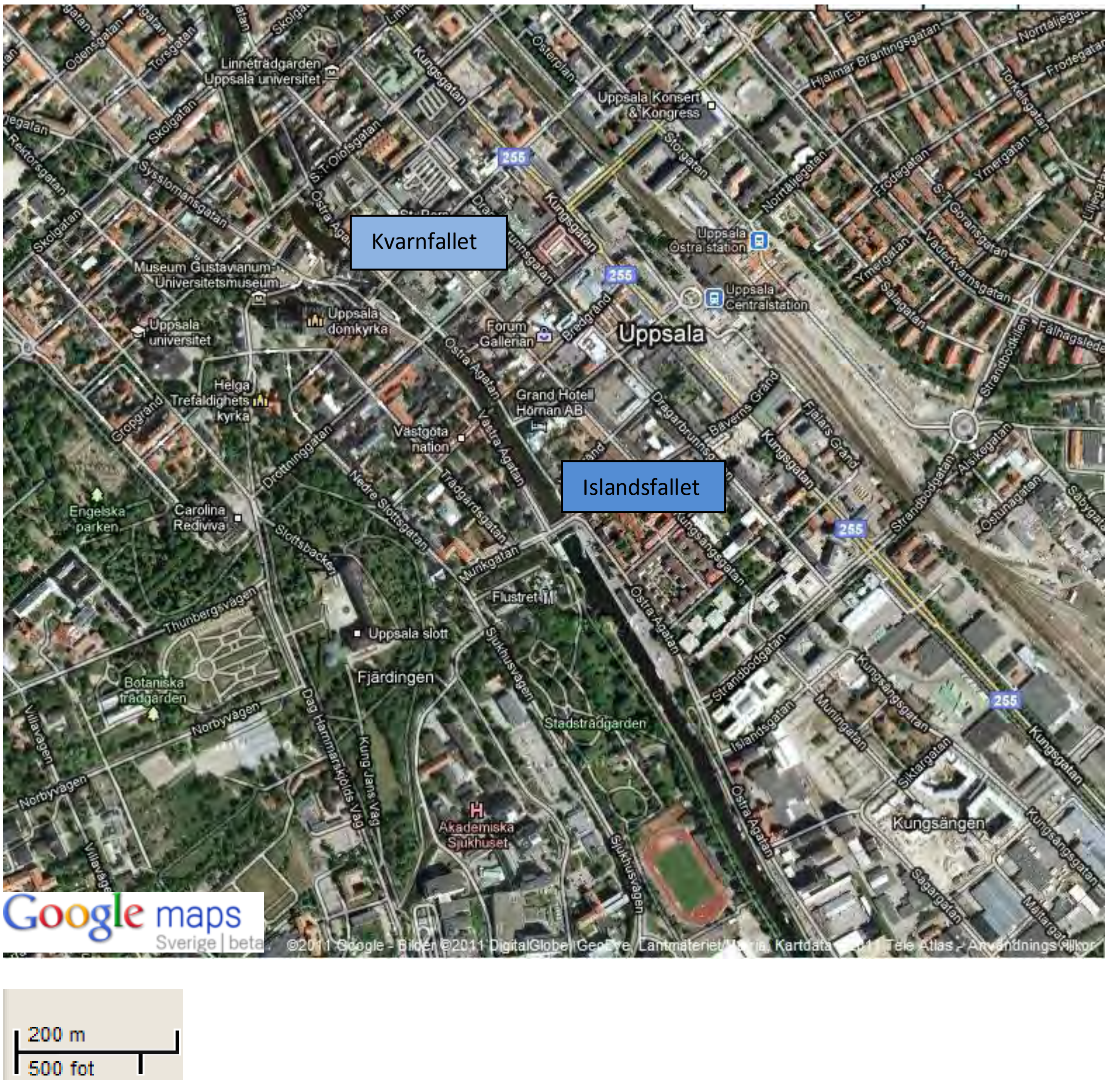
van Dijk P. L. M., Staaks G. & Hardweig I. (2001) The effect of fasting and refeeding on temperature preference, activity and growth of roach, *Rutilus rutilus*, Oceologica, **130**, 496-504

Vehanen T., Hyvärinen P., Johansson K. & Laaksonen T. (2006) Patterns of movement of adult northern pike (*Esox lucius* L.) in a regulated river, Ecology of freshwater fish, **15**, 154-160

Vøllestad L. A. & L'Abée-Lund J. H. (1987) Reproductive biology of stream-spawning roach *Rutilus rutilus*, Environmental Biology of fishes, **18**, 219-227

Worthington A. D., Macfarlane N. A. A. & Eastob K. W. (1982) Controlled reproduction in the roach (*Rutilus rutilus* L)

7. Appendix



Appendix. The two study areas Kvarnfallet and Islandsfallet both situated downtown Uppsala.