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Emigrating pike fry (*Esox lucius*) in coastal tributaries in the northern part of Uppland, Sweden

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Abstract

Predatory fishes such as pike (*Esox lucius*) and perch (*Perca fluviatilis*) have in some areas along the coast of the Baltic Sea shown to be under decline. The reason for this decline is not really known but exploitation of important habitats for spawning and nursery could be one of the explanations for weak recruitment. Shallow bays and wetlands in freshwater quickly becomes warm during spring, creating important habitats for spawning adults and fish larvae. Because of weak recruitment in local areas the main aim of this project was to investigate the production of pike fry in three wetlands. Habitat and food preference by small pike larvae were also investigated, information regarding this could be helpful in future restoration of wetlands. Special built traps were used in this study to estimate number, size and timing of emigrating pike larvae from three wetlands in northern Uppland, Sweden. The results revealed that pike fry start to emigrate from the wetlands just within a month after they have hatched. No pike larvae emigrated from one of the wetlands, Kavarö, due to early dry up in the wetland. The reason for this could be that the stream has been channelized. The difference in temperature between Hummelfjärden and Stenfjärden during emigration indicates that the temperature does not play a major role for pike larvae emigration. Wetlands are important nursery areas for small pike larvae. In this project habitat preference of pike larvae were investigated by using a white plate method. This method revealed that shallow flooded grass areas appeared to be the most preferred habitat by small pike larvae. It was also examined whether there were any differences between the three wetlands in terms of food resources, and in this study benthic fauna was used. Beside more mayflies (*Ephemeroptera*) in Hummelfjärden there were no differences between the wetlands. Obstacles in the streams that could hinder migrating pike from reaching their spawning areas were also investigated. Hummelfjärden has a floodgate that completely prevent migrating fishes from reaching spawning areas further up in the system but to what extent this affect emigrating pike larvae should be investigated. Kavarö and Stenfjärden did not have any obstacles in the streams. This study show that freshwater wetlands along the coast could contribute to increase pike population in the Baltic Sea and that human exploitations like in Kavarö could have an effect on pike recruitment.

Keywords: Emigrating pike fry, spawning pike, Baltic Sea, *Esox lucius*, wetlands

Introduction

Wetlands are highly diverse and among the most productive ecosystems worldwide. They can be permanent, like shallow lakes and ponds, or be of a more seasonal character such as flooded vegetation in shorelines of lakes and rivers. Wetlands can be found both in freshwater and in marine environments such as in archipelagos of the Baltic Sea (Barendregt et al. 2006; Burton and Tiner 2009; Hamilton 2009). These aquatic habitats provide many important services such as controlling flooding, water storage as well as shaping essential habitats for many kinds of fish (Burton and Tiner 2009). They also function as barriers between different ecosystems and act as important corridors for animal and plant dispersal (Brönmark and Hansson 2005; Covich 2009). Wetlands also serve as nutrient traps preventing nutrient transport from the drainage area to lakes and seas (Fisher and Acreman 2004; Brönmark and Hansson 2005). Nutrients like phosphorous and nitrogen entering the wetland could either be reduced by sedimentation (primarily phosphorous) or taken up by freshwater plants. Nitrogen could also be reduced by bacteria by the process of denitrification and leave the wetland in to the atmosphere as nitrogen gas (Brönmark and Hansson 2005; Jones and Downing 2009).

Shallow aquatic environments usually hold a high biodiversity and serve as important habitat for a wide range of species of animals and plants (Covich 2009; Uzarski et al. 2009). Due to the shallowness of these environments, the cover of vegetation, high productivity and higher temperature these habitats offer suitable spawning and nursery habitats for many different species of freshwater fish (Casselman and Lewis 1996). Coastal lakes, rivers, marshes, wetlands and bay areas are naturally flooded in spring creating suitable recruitment areas for anadromous migrating fish (Nilsson 2006; Findlay 2009). Anadromous fish mature and lives in saltwater but migrate in tributaries to reach their breeding grounds in freshwater (Winfield 2009). Roach (*Rutilus rutilus*), crucian carp (*Carassius carassius*), ide (*Leuciscus idus*), bream (*Abramis brama*), perch (*Perca fluviatilis*) and northern pike are all freshwater fishes that show an anadromous behavior and migrate from the Baltic Sea up in small coastal streams and tributaries to reach suitable breeding grounds in freshwater (Muller and Berg 1982; Casselman and Lewis 1996; Engstedt et al. 2011). In recent decades wetlands and rivers entering the coast of the Baltic Sea have been under different threats. Anthropogenic activities such as agriculture, eutrophication and physical exploitations have for example altered and destroyed many suitable and important habitats for spawning fishes (Hagerberg et al. 2004; Sandström et al. 2005; Hamilton 2009; Uzarski et al. 2009). Wetlands have been drained and rivers have been straightened and channelized (Jansson and Dahlberg 1999; Bobbink et al. 2006; Ljunggren et al. 2011). This has affected the organisms that utilize these important habitats negatively (Burton and Tiner 2009). Beside loss of suitable nursery and breeding grounds in freshwater, various types of obstacles in streams and rivers could hinder or completely prevent migrating fish from reaching their breeding grounds in freshwater. Building of dams and culverts or overgrown creeks caused by eutrophication may block these important passages (Hagerberg et al. 2004; Uzarski et al. 2009; Ljunggren et al. 2011). A species that is recognized as being under decline in the Baltic Sea is the northern pike (Nilsson et al. 2004; Lehtonen et al. 2009; Ljunggren et al. 2010). The northern pike is a freshwater fish that utilizes both freshwater and the coastal zones of the Baltic Sea as spawning and recruitment grounds. In earlier studies the decline has been suggested to partly been caused by a recruitment failure along the Baltic coast (Nilsson et al. 2004; Ljunggren et al. 2010). The reasons for the decline could, however, be many, as for example increased eutrophication, constructions of harbors and piers, overexploitation and change in the offshore ecosystem in the Baltic leading to shortage of food and/or increased predation pressure (Nilsson et al. 2004; Sandström et al. 2005; Ljunggren et al. 2010). Changes in the offshore food web in the Baltic Sea could have affected pike recruitment along the coast. Cod (*Gadus morhua*) is the dominating top predator in the offshore food web of the Baltic Sea, but due to overfishing and unfavorable climatic conditions the population has decreased (Casini et al. 2008; Mollmann et al. 2008). This has had a substantial influence on the Baltic ecosystem leading to cascading effects down the food-web (Casini et al. 2008; Ljunggren et al. 2010). The Baltic Sea has changed from being dominated by cod as predatory species, to a system that is dominated by planktivorous fishes such as the sprat (*Sprattus sprattus*). Increased sprat biomass has been hypothesized to have led to an increased competition for available food resources for medium sized and small fishes like juvenile pike (Ljunggren et al. 2010)..

Another planktivorous fish species that have exhibited a remarkable increase in recent years in the Baltic Sea is the three-spined stickleback (*Gasterostues aculeatus*) (Ljunggren et al. 2010; Bergström et al, unpublished manuscript). Sticklebacks utilize both the offshore and coastal ecosystem in the Baltic, and spawn during the same time in the very same shallow coastal bays as pike (Ljunggren et al. 2010; personal observation). Sticklebacks have been shown to be an effective predator on pike eggs and larvae but may also compete for shared food resources (Nilsson et al. 2004; Nilsson 2006). Studies conducted by Nilsson (2006) in the Kalmar sound area have shown that the three-spined stickleback could predate on pike roe and hence influence the recruitment of pike in local areas.

In early spring just after the ice break (in April-May) when the water temperature reaches 8-12 °C, pike and other freshwater fishes in the Baltic start to migrate upstream in tributaries (Raat 1988; Casselman and Lewis 1996; Kullander et al. 2012). Studies analyzing the chemical composition of pike otoliths have shown that 45% of the analyzed pike was recruited in freshwater (Engstedt et al. 2010). There is, however, substantial difference in this contribution across areas. According to studies that have been done in the Kalmar sound shallow areas with high cover of vegetation both in freshwater and saltwater are important for northern pike as breeding grounds (Ljunggren et al. 2011). Some areas that are shown to be especially important are existing grass areas that are flooded during high water levels in spring (Casselman and Lewis 1996; Craig 1996; Ljunggren et al. 2011). High water temperature and high cover of vegetation offers favorable conditions for production of zooplankton and benthic animals, which is an important source of food for the pike larvae (Casselman and Lewis 1996; Craig 1996; Nunn et al. 2012). In nursery habitats, macrophytes are also very important for reducing the risk of predation from other fishes but also function as shelter for the pike when they are hunting and attacking their prey (Bry 1996; Casselman and Lewis 1996; Lehtonen et al. 2009). After hatching within a period of a month the majority of the pike juveniles start to migrate back to the Baltic Sea (Nilsson et al. 2011, unpublished manuscript). The reason for this early migration is likely to avoid being trapped in shallow areas when the water retreats but also to avoid competition and predation, mainly from other pike individuals. Even very small pike individuals (just a few centimeters) show a cannibalistic behavior (Morrow and Miller 1998). Despite the substantial decrease of natural wetlands along the Baltic coast during the last centuries, this alone cannot explain a weak recruitment and declining stocks of pike due to the mismatch in timing (Ljunggren et al. 2011). Restoration of wetlands for pike recruitment might, however, offer a potential management solution to strengthen pike stocks along the coast and creation of new wetland is an important tool in conservation biology. It is important to consider the ecology of the species that utilize this habitat. For pike, for example, it is crucial to create wetlands suitable that serves both as spawning ground but also as nursery grounds (Nilsson et al. 2011; Nunn et al. 2012).

The main objective of this thesis was to investigate the habitat preference and production of pike fry in three different wetlands (Kavarö, Stenfjärden, and Hummelfjärden) along the southern Bothnian Sea coast. The specific aims were

i. To assess to what extent obstacles in the streams prevented migrating fish from reaching their spawning grounds and estimate number of migrating adults

ii. To quantify the extent of benthic fauna as food recourse for pike fry in the nursery grounds

iii. To assess habitat preference of pike fry in the wetlands

iv. To estimate the number and size of emigrating pike larvae from freshwater tributaries and wetlands, and also to assess the timing of emigration in relation to water temperature

v. To estimate if some pike juveniles remained in Hummelfjärden during the summer

Information about timing of migration, size at migration and habitat preference of pike fry could be helpful in future projects aiming at constructing wetlands to support pike stocks in the Baltic Sea.

Material and Methods

Study areas

The study was carried out in spring between April 23th and June 21th 2012. Three wetlands were chosen for the study, Kavarö, Stenfjärden and Hummelfjärden. They are all located along the shoreline of the Baltic Sea in the northeast of Uppland outside the county of Öregrund, Sweden (Fig.1). All three wetlands are connected to the Baltic Sea by small streams which are used as passage for anadromous fish during spring. These wetlands are used as spawning grounds by anadromous fishes like the Northern pike. Two of the wetlands are stable with permanent water bodies. The third wetland (Kavarö) is a temporary wetland and formed by flooded stream during high water levels in spring.

Location of Stenfjärden, Hummelfjärden and Kavarö

Figure 1. Location of Stenfjärden, Hummelfjärden and Kavarö in northern part of Uppland, Sweden. Maps: © Lantmäteriet: Permission I 2010/0058.

Kavarö

Kavarö is temporary wetland and is located just south of the city of Öregrund. Kavarö is an open grassland area which is seasonally flooded during spring. The vegetation consists mostly of different species of grasses and sedges such as common reed (*Phragmites sp*.) and different *Carex* species (Fig. 2b). The size of suitable spawning grounds varies between years depending on water levels. The length of the stream connecting the wetland with the sea is approximately 800 m and it is approximately 250 meters from sea to the spawning area. The width of the stream varies between 1- 2 m and the depth varies around 20-30 cm. The upper part of the stream that runs through the wetland is deeper because it has been channelized and straightened. The stream is mostly covered with dense belts of common reed (Fig 2a.). The water flow varies during spring and towards the summer it can get completely dry. The stream enters into the Sunnanöfjärden which is a sheltered bay (Fig .1). The area is not grazed by any cattle (Conny Söderqvist, personal communication).

Figure 2. (a) Upper part of the stream that runs through the spawning ground in Kavarö. (b) Grass area that is flooded during spring creating spawning areas for migrating fish. Photographs: Björn Averhed

Hummelfjärden

Hummelfjärden is located just outside the city of Öregrund and is a permanent wetland that has more the characteristic of a small lake (Fig. 1). The wetland is divided by a floodgate and creates two water bodies. The size of these two wetlands is eight and three hectares respectively. Hummelfjärden is surrounded by broadleaved forest with elements of coniferous trees. The shoreline is mostly covered by belts of common reed and in the western part the shoreline is covered with swamp forest with high abundance of alder (*Alnus glutinosa)*. The depths in the flooded swamp forest were around 20- 35 cm and the bottom was muddy and covered with organic matter, mostly leaves and sticks. The shoreline on the eastern part is covered by common reed and *Typha* species, and in some areas the mat/quagmire has grown so thick that trees/shrubbery such as birch has started to grow here. The water depths in this area were around 20- 40 cm. The water body in summer is much depressed by common reed and only small parts is open water. In the upper part of Hummelfjärden above the floodgate the size of the lake is 8 hectare (Fig.3a). In the northern part and in western part of the bay the vegetation consists mostly of common reed and the depth during spring varied between 10- 50 cm near the shoreline. On the other side of the western part of Hummelfjärden the vegetation consists mostly of common reed but there are areas with water horsetail and the depth varied between 20- 50 cm. The stream that connects Hummelfjärden to the Baltic Sea is about 35 m long and has a width between 0.75 -1.40 m. The depth was around 20-30 cm during the investigation period (Fig. 3b).

Figure 3. (a) Upstream the floodgate in Hummelfjärden. (b) The stream where anadromous fish use to reach their breeding grounds in Hummelfjärden. Photographs: Björn Averhed

Stenfjärden

Stenfjärden is located north of the city of Öregrund and is the largest of the three wetlands (Fig.1). Stenfjärden is a permanent lake with a size of 13 ha. The shoreline consists mostly of stands of common reed but also other reeds and sedges are present (Fig.4a). The surroundings are flooded during high water levels in spring. At northeast and northwest of Stenfjärden there are areas with marshes that consist of common reed and small birches. The lake has two streams that's enters the Baltic Sea. In the northern part, at the inlet of the two streams there is a swampforest that consists of mostly two tree species, alder (*Alnus glutinosa*) and birch (*Betula pendula*). Further out in the lake, large areas of common reed are more common. The depth varies between 10- 50 cm. At the western part of Stenfjärden there is big area of marshes with common reed. There are small areas of open water and the depth varies between 10- 30 cm.

In the southern and the eastern part there are big areas of common reed and marshes. One of the two streams is 280 m long has a width of 1.3-1.6 m and has a mean depth of 23 cm (Fig.4b). The other stream is 200 m long and has a width of 1.1-1.5 m and has a mean depth of 21 cm.

Figure 4. (a) Stenfjärden is surrounded by dense belts of *Phragmites australis.* (b) Fish trap in Stenfjärden in stream nr 2. Photographs: Björn Averhed

Obstacles to migration and migrating adults

The streams where investigated visually for obstacles such as culverts, dams, floodgates or vegetation that could hinder or completely prevent migrating fish from reaching their breeding grounds. In Hummelfjärden and Kavarö fyke nets were placed in the stream to estimate the number of fish that migrates up in these systems. Stenfjärden was visual scanned for migrating and spawning pike in the connecting streams (Fig. 5). In Hummelfjärden the fyke net was placed below the floodgate. This was done between March 23th and May 17th 2012. All fish that was trapped in the fyke net were identified to species level, measured and released above the floodgate and this was conducted by private people in Öregrund. In Kavarö the fyke net was placed downstream the spawning ground. Fish were trapped between March 22th and April 30th and identified to species level, measured and released above the fyke net so they could continue their migration to the spawning ground. This fieldwork was conducted by the landowner (Conny Söderqvist) of Kavarö.

Figure 5. Migrating pike in Stenfjärdsbäcken April 24th with a temperature of 7- 8 degrees. Photographs: Björn Averhed

Quantification of benthic fauna

To investigate the extent of benthic fauna as a food resource for the pike larvae, a core sample was used. Two sampling areas were chosen in two different habitats (Common reed and Swampforest) in Hummelfjärden and Stenfjärden, and in Kavarö areas of common reed and in the stream. Within each sampling area, four subsamples were taken making it a total of eight samples per wetland. The samples were placed in small buckets and transported to the lab. The samples were preserved in 95 % ethanol for later identification under a stereo microscope (Olympus SZ61). As literature for identification of the benthic fauna, Aquatic insect of North Europe volume 1-2 (Nilsson 1996; Nilsson 1997) was used. After species identification, total abundance/m^2, the Simpson's diversity index and total biomass/m^2 were calculated in each wetland and habitat. Abundance and biomass per group was also calculated for the largest benthic fauna groups, in this case *Ephemeroptera* (Mayflies) and *Chironomidae*, using length/weight regressions (Eklöv and Svanbäck, unpublished).

Habitat preference of pike larvae

To estimate the abundance and habitat preference of pike larvae in the wetland, the white plate method was used (Lappalainen et al. 2008). This method is carried out by wading in shallow water and slowly placing a 25 cm diameter plastic white plate attached to a 1.5 m stick 10-30 cm under water and counting all newly hatched larvae visible against the white background (Fig. 6). The method is preferably used when the pike is small such as in the yolk-sac stage (Fig. 6). At each wetland four transects with five stops were selected making in total 20 samples per wetland. These transects were placed in four different areas that contained habitats like common reeds, swampforest, shrubbery areas and grassy areas, and in Hummelfjärden also in areas with water horsetail. The method was used at three occasions at the same transects separated by 7 days at May 10th, 17th and 25th. At each stop, information such as number of pike larvae, vegetation type and water depth was recorded.

Figure 6. (a) White plate method used in Stenfjärden. (a) Small pike larvae in yolk-sac stage. With the plate method it is easier to detect the small pike larvae against the white background. Photographs: Björn Averhed

Number and size of emigrating pike

To quantify pike emigration from the wetlands a fish trap was placed downstream near the outlet of each wetland (Fig. 7a). One fish trap was placed at each of the two stream outlet from Stenfjärden. The traps were specially built for catching emigrating pike fry and placed in the streams on the April ^{23th} and were removed in June 21th. The traps were 51×51cm made of Plexiglas and at the end of each trap there was a dense net with a removable 5 liter container (Fig. 7a). When the pike fry migrates back to the Baltic Sea they flow with the current and ends up in the container which can be removed and emptied (Fig. 7b). It is important to make sure that the trap not covers the whole stream so that larger fish and other animals could move freely in the stream. To prevent the trap from drifting away which could easily happen in the spring flood stones were placed inside the trap. The upper 20 cm of the trap was always above the water surface in case of changing water levels. The traps were emptied at least once a day depending on the amount of fry emigration. During intense periods the trap was emptied twice a day. Even if there was no fry in the trap it was important to clear the trap from vegetation that otherwise could prevent the fry from entering the traps. Fry that was caught was identified to species level, measured and then released. All fish that was caught was always handled with care and in water. Between April 11th and November ^{5th} temperature loggers were placed in the streams/wetland. Temperature loggers were also placed at the stream outlets in the wetlands and the temperature measurements were recorded every two hours.

Figure 7. (a) Fish trap in stream nr 1 in Stenskär. (b) Small pike fry which has been caught in Stenfjärden. Photographs: Björn Averhed

Young of the year (Y-O-Y) in Hummelfjärden

To investigate if any young of the year pike stayed in Hummelfjärden small underwater detonations were used. This method involves detonations with 10 g of explosives that are attached to a fishing rod (Snickars et al. 2007). The detonation was conducted at 0.5 meter under the surface at four locations in Hummelfjärden. All fish within a few square meters of the detonation are either stunned or killed. All fish that floated up to the surface were collected. Fish that sank to the bottom were collected by a diver. All fish was identified and measured. This method was conducted by licensed people at the Institute of Coastal Research (Swedish Agriculture University) in Öregrund.

Statistical analyses

To assess if there was any difference between the wetlands in with respect to food resources and habitat preference of pike larvae a one-way ANOVA (Analysis of Variance) test was used with Tukey's post hoc tests. T-tests (assuming unequal variances) were used to see if there were any differences in size of pike larvae and in temperatures between the three wetlands. Regression analyses were used to see if there were any correlation between fry emigration and temperature. Transformation (ln+1) of data was done when needed. STATISTICA 10 and Excel 2010 were used for statistical calculations. The graphs were done in Excel 2010 and maps were done in ArcGIS.

Results

Obstacles to migration and migrating adults

In Hummelfjärden there are two obstacles that could hinder migrating fish from reaching their spawning areas. These could either be a small dam that could be a hinder for migrating fish depending on water levels (Fig. 9a), or a floodgate that completely stops migrating fish from reaching the system up-stream (Fig. 9b). No big obstacles to migration could be found in Stenfjärden and Kavarö.

Figure 9. (a) Downstream the floodgate there is a small dam in Hummelfjärden. (b) Floodgate in Hummelfjärden that completely stop migrating fishes. Photographs: Björn Averhed

Hummelfjärden

Between March 23th and May 17th 75 pike were caught in the fyke net. Pike migration peaked on April 17th when 15 pike were trapped in the fyke net (Fig.10). In addition to the pike, a total of 589 perch were also caught during the investigation period, and the peak in abundance occurred during the first four days in May (Fig.10). Also, 1679 roach (*Rutilus rutilus*) were caught and the peak occurred on May 3rd when 442 roach were caught (Fig.10)

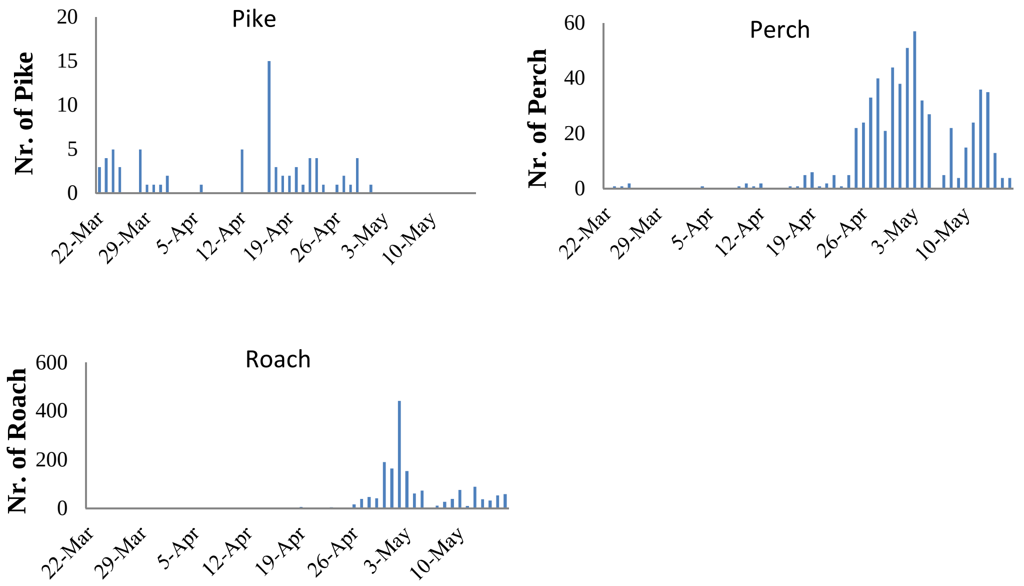


Figure 10. Number of migrating adult pike, perch and roach in Hummelfjärden

Kavarö

Between March 22th and May 1th, 35 pike were caught in the fyke net. The peak was on March 24th when 7 pike were caught (Fig.11). In addition to this, 36 perch were caught in Kavarö and the peak was in April 16-17th (Fig.11). At the end of April and beginning of May, numerous European smelt (*Osmerus eperlanus*) were caught in the fyke net.

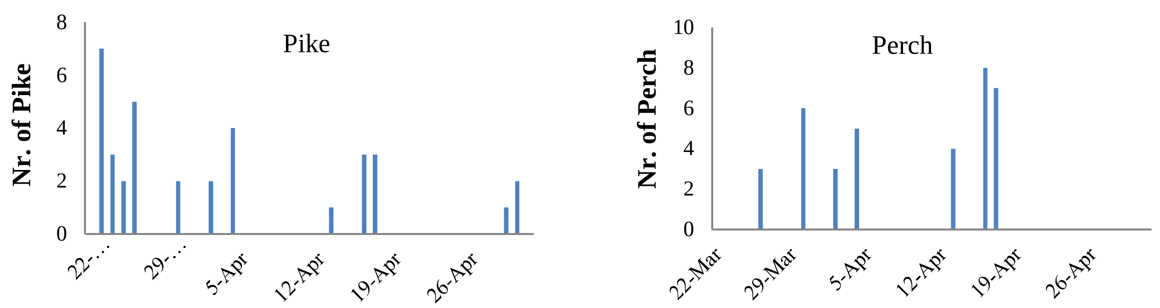


Figure 11. Number of migrating Pike and Perch in Kavarö

Quantification of benthic fauna

There was no difference in species abundance (ANOVA, $F = 3.22$, $p = 0.06$), biomass (ANOVA, $F = 2.52$, $p = 0.11$) or in Simpson's diversity index (ANOVA, $F = 0.44$, $p = 0.65$) between the three wetlands with respect to benthic invertebrates. The two most abundant groups of benthic invertebrates that were found within the three wetlands were *Ephemeroptera* (mayflies) and *Chironomidae* (nonbiting midges). There were no differences in abundance of *Chironomidae* between Hummelfjärden, Stenfjärden and Kavarö (ANOVA, F= 0.50, p=0.61) (Fig12). There was, however, a significant difference in the abundance of *Ephemeroptera* between the three wetlands (ANOVA, $F = 7.36$, $p = 0.005$) (Fig. 12) The abundance of *Ephemeroptera* was higher in Hummelfjärden than in both Stenfjärden (ANOVA with Tukey's test, $p = 0.007$) and Kavarö (ANOVA with Tukey's test, $p =0.03$) (Table 1).There were no differences in *Ephemeroptera* abundance between Stenfjärden and Kavarö (ANOVA with Tukey's test, p = 0. 99).

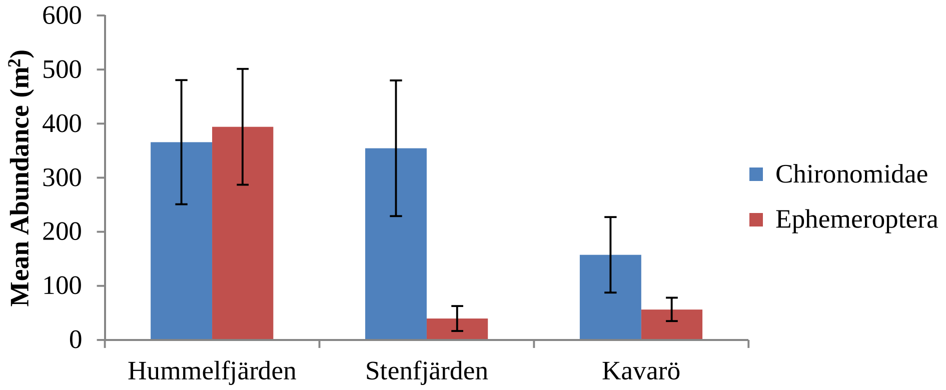


Figure 12. Number/m^2 of *Ephemeroptera* and *Chironomidae* in Hummelfjärden, Stenfjärden and Kavarö. Mean values ± standard error are displayed

Habitat preference of pike larvae

Stenfjärden

A total of 46 pike larvae were detected using the white plate method in Stenfjärden, and 44 of those larvae were found in shallow, sun exposed areas with emergent grass (Fig. 13*)*. Most of the larvae were in the yolk-sac stage and not free swimming. The majority of the larvae were found on the first visit on May 10th 2012. An ANOVA showed a significant difference in habitat preference of pike larvae across the four habitats sampled (F= 6.36, p= 0.00087). As such, shallow habitats with flooded grass areas were shown to be most used as habitat by small pike larvae in Stenfjärden.

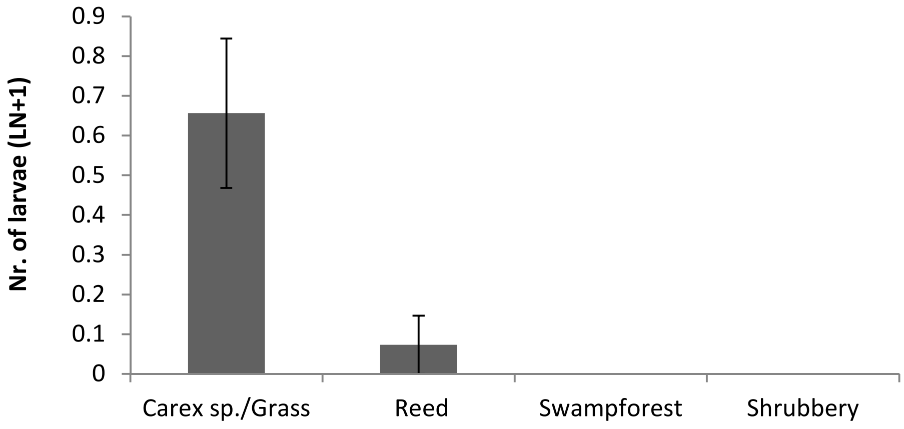


Figure 13. The bars with standard error show the mean number (LN+1) of pike larvae that were found with the white plate method in the different habitats of Stenfjärden.

Hummelfjärden

Only five pike larvae were found in Hummelfjärden using the white plate method. No pike larvae were found in the flooded swampforest. ANOVA showed no difference between habitats in Hummelfjärden (F=3.56, p= 0.11).

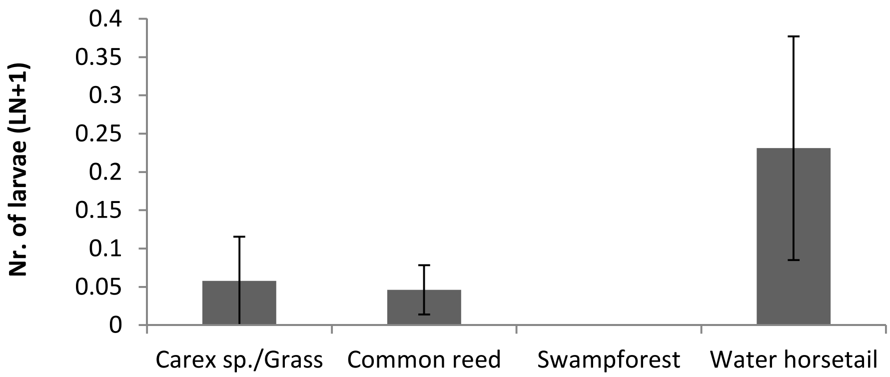


Figure 14. The bars with standard error show the number (LN+1) of pike larvae that was found with the white plate method in different habitats of Hummelfjärden.

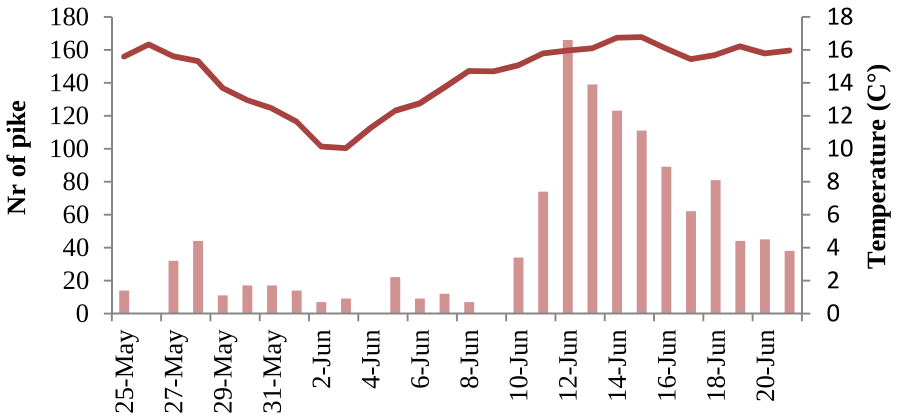
Kavarö

No pike larvae were found in Kavarö. The wetland was almost dry at the time of hatching. The white plate was, however, used in the existing stream but no pike could be detected here.

Number, size and timing of emigrating pike larvae in relation to water temperature

Stenfjärden

The temperatures in Stenfjärden were with the exception of a dip in late May and early June stable throughout the whole investigation period (Fig. 15a). Emigration of pike larvae started in May 25th and the peak of pike emigration was during 12-13th June when temperature had reached 16 °C. After June 13th, the number of migrating pike declined. A total of 1183 emigrating pike juveniles were caught in the two streams in Stenfjärden. The temperatures were also significantly higher in Stenfjärden than in Hummelfjärden (p = <0.001). The first emigrating pike larvae that were caught had a mean size of 18.6 mm, and the larvae grew linearly until the last day of sampling. The mean size on June 21th was 52 mm and the pike larvae grew approximately 1.20 mm each day. The pike larvae were significantly larger in Stenfjärden than in Hummelfjärden (p= <0.006). No correlation between migrating pike and temperature could be detected.



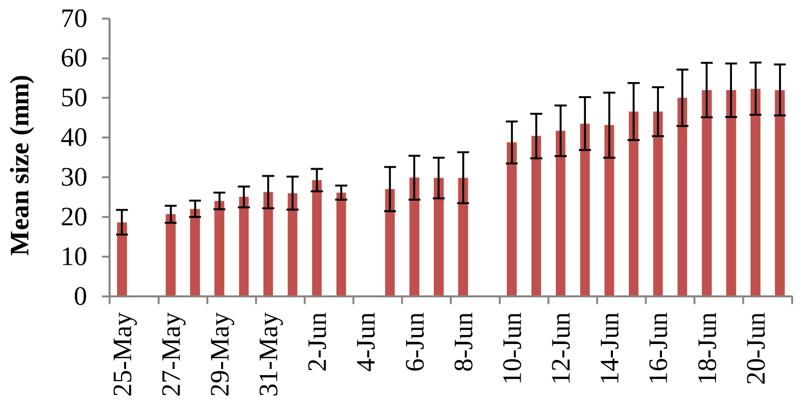
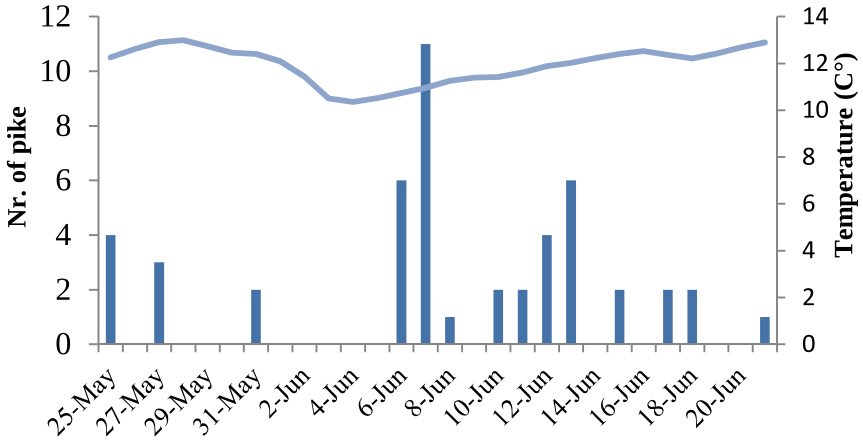


Figure 15. (a) The bars show numbers of emigrating pike from both streams that were caught and the line display the water temperature C ° in Stenfjärden between May 25th and June 21th. (b) The bars show the mean size (±SD) of emigrating pike juveniles that were caught in the fish trap in Stenfjärden between May 25th and June 21th 2013

Hummelfjärden

The first emigrating pike larvae in Hummelfjärden were caught on May 25th, the same date as in Stenfjärden. A total of 49 emigrating pike larvae were caught in Hummelfjärden. The peak of migration was on June 7th when 12 pike were caught at a temperature around 11 °C (Fig. 16a). The mean water temperature during the investigation period in Hummelfjärden was stable and around 12 °C. The temperature was significantly lower in Hummelfjärden during the investigation period than in Stenfjärden ($p = <0.001$). The first four pikes had a mean size of 15 mm, and the last pike larva that was caught was 38 mm long (Fig.16b). In Hummelfjärden the pike larvae grew approximately 0.80 mm each day. The pike larvae were significantly smaller in Hummelfjärden then in Stenfjärden ($p= <0.006$). No correlation between migrating pike and temperature could be detected.



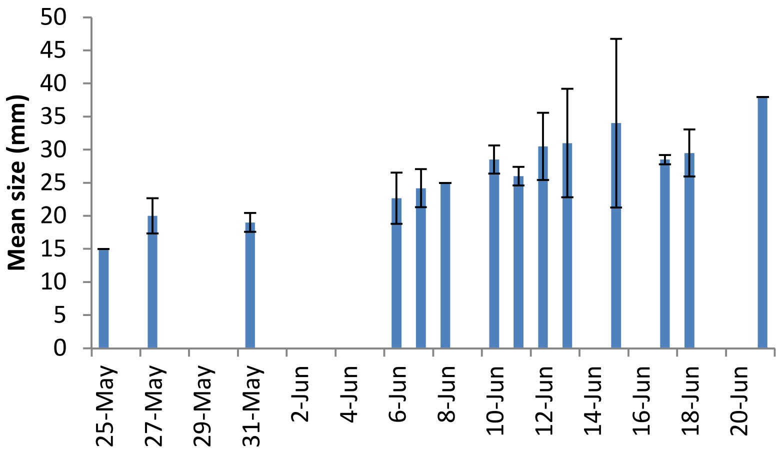


Figure 16. The bars show numbers of emigrating pike that were caught in the trap and the line display the water temperature C ° in Hummelfjärden between May 25th and June 21th (b) The bars show the mean size (±SD) of emigrating pike fry that were caught in the fish trap in Hummelfjärden between May 25th and June 21th 2013

Kavarö

No emigrating pike larvae were caught during the investigation period in Kavarö.

Young of the year (Y-O-Y) pike in Hummelfjärden

Underwater detonations revealed that some pike juvenile remained in the wetland over the summer. The mean length of the five pikes recorded was 18 cm. Besides catching pike, a total of 12 perch and 18 roach was caught (table. 2).

Table 2. To see if any juvenile pike remained in the wetland four detonations was conducted in Hummelfjärden.

Fish	Pike (*Esox lucius*)	Size (pike)	Perch (*Perca fluviatilis*)	Roach (*Rutilus rutilus*)
Detonation 1	2	24.7 cm, 12.3 cm		
Detonation 2	1	22 cm		
Detonation 3			1	18
Detonation 4	1	13.1 cm	11	

Discussion

Migrating adults

Fish undertake migration for several reasons. The reason could be because of changes in environmental conditions, search for better feeding grounds, to avoid predation, but also for reproduction (Winfield 2009). Migration could be on a small scale between different habitats within lakes and rivers in their search for food or to avoid predation (Brönmark et al. 2008; Winfield 2009), but also on a larger scale such as the Atlantic salmon (*Salmo salar*) that travels hundreds of kilometers to reach breeding grounds in freshwater (Winfield 2009). Spawning migration is probably the most known and spectacular reason for fish migration. Freshwater fishes in the Baltic Sea like pike, perch and common roach undertake shorter migrations during spring and travel up in small tributaries for spawning. In this study I show that Stenfjärden, Hummelfjärden and Kavarö in focus are all used as spawning ground by migrating pike from the Baltic Sea. One reason for this migration in coastal freshwater streams could be that freshwater systems offer more favorable conditions and habitats in terms of spawning and nursery areas than the brackish water of the Baltic Sea (Muller and Berg 1982). Different kinds of hinder could prevent anadromous fishes from reaching their breeding grounds in freshwater. In Stenfjärden and Kavarö there were no obstacles for migrating fish but in Hummelfjärden there are two obstacles. Migrating fish in Hummelfjärden must be transferred with fyke nets over the floodgate by man if they should be able to reach breeding ground further up in the system.

Food resources for pike larvae

Flooding in freshwater caused by high water levels during spring create a suitable spawning habitat for the Northern pike (Ljunggren et al 2011). Flooded shallow areas with high cover of vegetation are important not only as spawning areas but also as nursery grounds. Submerged, emerged and floating vegetation creates a complex environment which is important for young pike (Raat 1988; Casselman and Lewis 1996; Ljunggren et al 2011). Shallow areas are heated quickly during spring and this favors production of vegetation, zooplankton and benthic fauna which is an important food resource for pike fry especially in the early life (Bry 1996; Casselman and Lewis 1996; Nunn et al. 2012). Another advantage with spawning in freshwater is that freshwater zooplankton seems to be of higher quality than zooplankton in brackish water in the Baltic Sea (Engström-Öst et al. 2005). My study showed no overall differences between the three wetlands when it comes to total biomass, diversity of benthic invertebrates. Hummelfjärden showed a tendency of containing higher abundance of benthic invertebrate but no significant difference could be detected. The two largest groups of benthic invertebrate in these wetlands were mayflies (*Ephemeroptera*), and non-biting midges (*Chironomidae*) which both are important food sources for pike larvae (Skov et al. 2003; Nilsson et al. 2011, unpublished manuscript). The abundances of *Ephemeroptera* in Hummelfjärden were significantly higher than in Stenfjärden and Kavarö, but there were no difference in abundance of chironomidae between the wetlands. During the first week the pike larvae depends on its yolk-sac as a nutrient source and as soon as the yolk-sac is consumed, they immediately start to use exogenous food intake (Billard 1996; Bry 1996; Morrow and Miller 1998; Inskip 1982). Studies have shown that during the first week of life, the diet of pike consists mostly of zooplankton and as the larvae grows larger they shift to a diet that consists more of *Chironomidae* larvae and other aquatic insects such as *Ephemeroptera* (Bry 1996; Skov et al. 2003). I show that in the investigated wetlands, there was suitable food available for the small pike larvae when it comes to benthic fauna. Wetlands that have high production of zooplankton and benthic fauna at time when pike larvae hatch could probably harbor more pike larvae and contribute to a higher production of juvenile pike stronger Y-O-Y stock in the Baltic Sea (Ljunggren et al 2011). In this study however, there were more emigrating pike larvae in Stenfjärden than in Hummelfjärden, but the highest abundance of *Ephemeroptera* was found in Hummelfjärden. One explanation for this could be that due to the higher food densities, pike larvae did not chose to migrate out from Hummelfjärden. A lower density of *Ephemeroptera* in Stenfjärden might also be due to a higher density of pike larvae suppressing the food resources, or that other factors than the density of benthic fauna, as for example the extent of flooded vegetation, was more important for the production of pike larvae.

Habitat preference

No pike larvae could be detected in Kavarö since the wetland was dry at the time of sampling. The most preferably habitat for pike fry in Stenfjärden was in sheltered shallow, sun exposed areas with emergent grass/carex. Previous studies have also shown that shallow sheltered areas with emergent grass and sedges are the most suitable habitat for young pike larvae (Casselman and Lewis 1996). These environments provide shelter and food but also offer good substrate for the pike egg (Bry 1996; Ljunggren et al. 2011), since it is important that the eggs are kept away from the bottom where anoxic condition could develop (Casselman and Lewis 1996). Deeper water and areas with common reed and shrubbery vegetation and flooded swamp forest in Stenfjärden was shown to be less selected by pike larvae. In

Hummelfjärden, shallow sun-exposed areas with grass and sedges are few and only one pike larvae was found in these habitats. Two larvae were found in areas with common reed and two were found in water horse tail. Potential spawning habitats in Hummelfjärden consist mostly of flooded areas with common reed. My results clearly show that shallow sheltered areas with grass and carex was the most attractive habitat. If this is a general pattern, these kinds of habitats should be favored and created in wetland management. Swampforest and shrubbery areas in these two wetlands were shown to be less attractive. The bottom in this flooded swampforest was covered with decaying leaves and sticks, with little sunlight reaching the water surface. This is probably not a suitable environment for fast growing pike larvae. As the pike larvae grow bigger they also need to expand to deeper water (Casselman and Lewis 1996) and this could be a reason that almost no larvae were found during week two and three of the investigation period.

Emigration of juveniles

Previous studies in Kalmar strait have shown that a large proportion of all pike fry that hatched in the wetlands chose to migrate back to the Baltic Sea within one month (Nilsson et al. 2011, unpublished manuscript; Ljunggren et al. 2011). This is probably a way to maximize their chance of survival by avoiding starvation/competition and cannibalism in the wetland (Ljunggren et al. 2011). The first emigrating pike larvae were caught on May 25th in Stenfjärden at a temperature of 16 °C. The peak of emigration occurred in June 12-13th. Pike larvae small as 14 mm were caught in the trap in this area. This shows that as soon as the larvae are able to swim, some choose to migrate back directly to the Baltic Sea. This early migration could be to avoid predation by other pikes (Morrow and Miller 1998) or avoid competition or the risk of being trapped in small water cavities when the spring flooding retreats (Nilsson et al. 2011, unpublished manuscript; Ljunggren et al. 2011). The first migrating pike larvae in Hummelfjärden were also caught on May 25th. The mean size was 15 mm on the first day of migration at a temperature of 12.3 °C. The temperature was lower in Hummelfjärden throughout the whole investigation period and there was significant difference in size between the two wetlands. Pike larvae were significantly smaller in Hummelfjärden than in Stenfjärden. Pike larvae grow rapidly and in Stenfjärden they grew around 1.20 mm each day and in Hummelfjärden the larvae grew around 0.80 mm each day. Higher temperature in Stenfjärden could be an explanation for faster growing pike larvae (Raat 1988; Bry et al. 1991; Casselman and Lewis 1996). The food resources were high in both wetlands so food resources were probably not the reason for the difference in growth of the pike larvae. The emigration from Hummelfjärden and Stenfjärden started at the same day at different temperature so the temperature did not seem to be the trigger for this early migration. Stenfjärden has more flooded vegetation hence more suitable nursery areas than Hummelfjärden and this could be one explanation why there were more pike larvae in Stenfjärden (Casselman and Lewis 1996)..

There could be several reasons why there was low emigration rate in Hummelfjärden. Abiotic factors could be one explanation, like low temperature, change in oxygen and water levels might affect pike roe and small larvae negatively (Casselman and Lewis 1996). Another reason could be that, emigration by pike larvae is a way to increase their chances of survival and if conditions are suitable there might be an advantage to remain in the nursery area (Casselman and Lewis 1996; Ljunggren et al. 2011). I show with the detonation method that some pike juveniles actually remained in the nursery areas during the summer in Hummelfjärden. Besides favorable environmental conditions, the floodgate in Hummelfjärden could also be a potential reason for low migration of juveniles. To what extent floodgates prevent emigration is not known, but studies on this issue should be conducted.

No pike fry were caught in Kavarö even though adult pike migrated in this system to spawn. That spawning actually took place was observed by the landowner (Conny Söderqvist, personal communication). A reasonable explanation why there was no production of pike or other fishes in Kavarö might be that the temporary wetland dried out too quickly in order for pike to grow and migrate out to deeper water for survival. Only small patches with water was left and these cavities of water had no connection with the nearby stream. The stream in Kavarö has been straightened and channelized for increasing the drainage in the area and this probably caused an early dry up of the wetland.

Suggestions on management of the wetlands investigated

Exploitation and eutrophication have both had an effect on pike recruitment along the coast of the Baltic Sea (Nilsson et al. 2004). In areas where there still are suitable spawning and nursery grounds for anadromous fish, different kinds of obstacles could prevent the fish from reaching these important habitats. In Stenfjärden there were no visual obstacles in the stream. There is a culvert in one of the streams but this didn't show to be a hinder for the pike. One possible obstacle in Stenfjärden for both adults and juveniles are the dense vegetation. The stream begins inside a dense swamp forest, and in some areas the vegetation starts to get very dense. One way to solve this problem would be to clear off some vegetation and make it easier for the adult pike to reach the spawning ground. This would also facilitate emigrating pike to reach the Baltic Sea.

In Kavarö there is a culvert and a dam which is open during spring and does not prevent migrating fish. A possible practical management measure in Kavarö is to recreate the meandering of the stream that might cause flooding, allow the water to stay a longer period in the wetland and hence to make the stream more natural in its appearance. Another way could be to create flooding by damming the stream during spring and prevent water retreat before the pike larvae have hatched. The Kavarö wetland consists mostly of different kind of grasses and should be a good breeding ground for pike, especially if the area also could be grazed by cattle.

In Hummelfjärden there are two obstacles that could prevent or make it more difficult for the fish to reach their spawning areas. At the outlet of the wetland there is a minor obstacle in form of a small dam. Depending on the water flow, it could be a hinder for migrating fish. Further up in the system there is an absolute stop in form of a floodgate that makes it impossible for the fish to pass. The only way for the fish to reach the spawning areas is to be transferred by man. At the smaller dam near the outlet to Baltic Sea, one solution could be to create a small pathway around the dam to make a clear pathway.

Conclusion

Kavarö, Hummelfjärden and Stenfjärden were all used as spawning ground by northern pike. By using special fish traps I show that pike larvae chose to emigrate shortly after they have hatched. Food resources and temperature didn't seem to be the cause of emigration in these three wetlands. Decreasing water level and cannibalism could be two reasons for this early emigration. Pike larvae were caught in Hummelfjärden and Stenfjärden but no pike larvae were caught in Kavarö even though adult pike spawned in the system. Results from this study have shown that human impact such as building of floodgates and channelization of streams actually has an effect on spawning and nursery areas. Wetlands along the coast of the Baltic Sea are important habitats for anadromous fishes and creating new and restoring degraded wetlands could be a good way to support and strengthen pike populations locally in the Baltic Sea.

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