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Upstream migration activity of cyprinids and percids in a channel, monitored by a horizontal split-beam echosounder

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Abstract

A 200 kHz digital echosounder (HTI) with two split-beam transducers was aimed horizontally to monitor the upstream migration activity of fish, from 24 April to 28 June, in Äijälänsalmi channel (mean width 35 m, length 700 m, and maximum depth 5 m) from large mesotrophic Lake Päijänne to small eutrophic Lake Jyväsjärvi. This study was part of a larger project which aims to analyse the movement of commercially unimportant fish species and reduce the abundance of these fish in L. Jyväsjärvi. Catch samples were collected with a trap net located immediately upstream from the acoustic beams. The most common species in the catch were roach (*Rutilus rutilus*), perch (*Perca fluviatilis*), bream (*Abramis brama*), ruffe (*Gymnocephalus cernuus*), and white bream (*Abramis bjoerkna*). The upstream migration of fish was correlated with water temperature (r = 0.40) with time lag of 1 d. In spring, L. Jyväsjärvi warmed faster than L. Päijänne, causing spawning migration from L. Päijänne to L. Jyväsjärvi. Clear diurnal rhythm in activity was observed. The migration rate through the channel peaked around dawn and dusk. Catch per unit effort of the trap net suggested that the peak of the spawning migration of different species was separate. Upstream migration was induced by the temperature difference between two lakes, and the activity of the migration was regulated by temperature changes and light rhythm.

Keywords: Horizontal acoustics; Migration; Temperature; Diel rhythm; Cyprinids; Percids

1. Introduction

The split-beam three-dimensional target tracking technique enables detection of the swimming direction and speed of individual fish in real time. This system also permits the study of migration changes in the short term. These systems are usually used to non-intrusively count upstream migration of anadromous salmonids returning up their parent river (Ransom et al., 1998). Fixed location hydroacoustic methods can also be used to study the diel behaviour and movements of fish on lakes and other shallow waters (Cuillard, 1998; Gonzalez and Gerlotto, 1998; Kubecka and Duncan, 1998a).

Fish migrations can be classified as reproductive, feeding and refuge migrations (Lucas and Baras, 2001). The timing of spawning migrations in freshwater is generally determined by light rhythm and temperature changes. The scale of migrations in freshwater habitats is usuallysmall compared to anadromous species, but it can be ecologically important. This study was the first attempt to assess the upstream migration of cyprinids and percids in a Finnish channel by using hydroacoustics.

A few decades ago, L. Jyväsjärvi was the dumping place of the city of Jyväskylä, and its water quality was extremely low. A water purification plant was completed in the end of 1970s and water quality began to improve. Currently, L. Jyväsjärvi is an important location for development, growth and reproduction of many commercially unimportant fish species. The aim of this study was to monitor the upstream migration of the commercially unimportant fish species through the Äijälänsalmi channel, and to identify the role of water temperature and air pressure affecting it.

2. Materials and methods

2.1. Study site

Äijälänsalmi channel is located in central Finland and connects L. Jyväsjärvi to L. Päijänne (Fig. 1). The channel is

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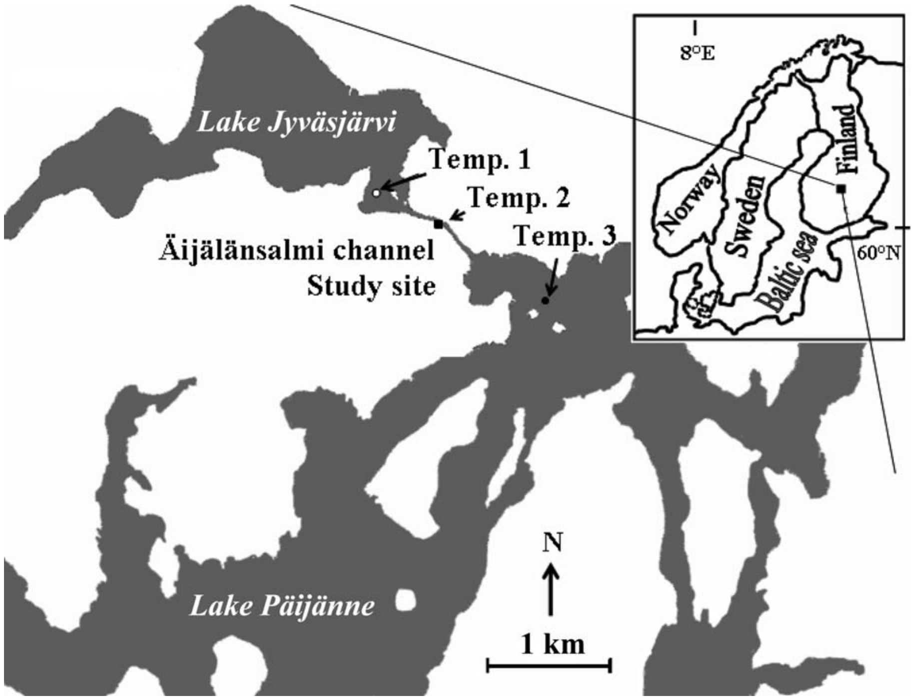

Fig. 1. Map of Äijälänsalmi channel, Lake Jyväsjärvi, and the northern part of Lake Päijänne. The arrows show the location of the hydroacoustic study site and the location of the temperature measurements (Temp. 1, 2, and 3).

700 m long and 4 m deep, with a width of about 30 m. The channel has been dredged, hence the bottom profile is quite similar throughout its length. The bottom substrate in the echosounding site consists generally of mud or clay. L. Jyväsjärvi discharges via the channel to L. Päijänne. During spring and earlysummer (April-June), the current is towards L. Päijänne, and is laminar. However, the direction of current in Äijälänsalmi channel can sometimes change, especially, in late summer. In winter, both the lakes and the channel are covered by ice.

L. Jyväsjärvi is eutrophic and northern L. Päijänne is mesotrophic (Table 1). The fish population in L. Jyväsjärvi and northern part of L. Päijänne consists mainly of roach (*Rutilus rutilus*), bream (*Abramis brama*), white bream (*Abramis bjoerkna*), perch (*Perca fluviatilis*) and ruffe (*Gymnocephalus cernuus*). The main predator species are pikeperch (*Sander lucioperca*) and pike (*Esox lucius*).

2.2. Hydroacoustic counting

A 200 kHz digital split-beam echosounder HTI (Hydroacoustic Technology, Inc.) Model 243 was used at a fixed location in this study. Two elliptical (4 × 10°) transducers were mounted across the channel, one for each bank, and once properly mounted, were kept stationary. The system also included dual-axis transducer rotators, an oscilloscope, a printer, and a computer. The transmitter pulse length was 1.25 ms and a 10 kHz frequency-modulated (FM) slide/chirped signal was used to maximize the signal-to-noise ratio (Ehrenberg and Torkelson, 2000). The sampling rate was 8 pings s^{-1} and a 40 log R TVG (Time Varied Gain) function was used. The sensitivity threshold value of the detected echoes was –58 dB (–52 dB at full beam) due to the low level of the background noise. Before and after the study, the echosounder system was in situ calibrated using a tungsten-carbide standard sphere (∅ = 38.1 mm). The echosounder was in operation 24 h a day and each hour was split into four sequences. Both transducers collected data in turn for 30 min every hour. On both banks, the position scanning was set at two vertical aiming angles, each scanning for 15 min. The rotator controllers communicated with the echosounder, processor, and dual-axis rotators to automatically scan pre-set of aiming angles. Aiming angles near the surface could not be used, due to boat traffic in the channel. The angles of the beams were defined by in situ beam mapping. They were on the north bank –21.7° (seq. 1) and –12.2° (seq. 2) and on the south bank –22.7° (seq. 3) and –13.2° (seq. 4) (Fig. 2). Guiding nets were used to exclude fish from swimming behind the transducers. Acoustic data were analysed by means of the analysis software HTI EchoScape. The auto-tracking mode was used, and auto-tracking parameters were tested with manual tracking. In all, 1567 hourly files were analysed between 24 April and 28 June.

Table 1
Hydrological characteristics of Lake Jyväsjärvi and Lake Päijänne

	Lake Jyväsjärvi	Lake Päijänne (northern part)
Area (km^2)	3.37	54
Maximum depth (m)	26	48
Total phosphorus (µg l^{-1})	35–40	15
Total nitrogen (µg l^{-1})	850	650
Colour (Pt mg l^{-1})	80–100	30–50
pH	6.9	6.9

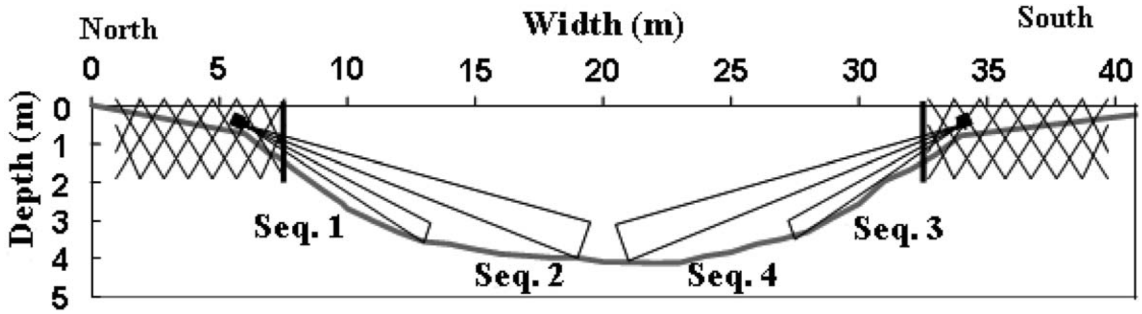

Fig. 2. The cross-sectional view of Äijälänsalmi channel. Two transducers with elliptical beams were aimed sloping downward. Guide nets kept the fish from swimming behind the transducers. Acoustic data were collected at four sampling periods per hour (seq. 1–4).

2.3. Trap net catch and environmental variables

The species and length distribution of migrating fish populations were estimated from trap net catches. The trap net was placed 50 m towards L. Jyväsjärvi from the echosounding site, and was set to catch fish migrating upstream to L. Jyväsjärvi. The trap net was sampled from 26 April to 28 June. It was examined at 1–7 d intervals. The length and species distribution of each catch were measured. The total length of each fish was measured to the nearest mm. If the total catch exceeded 10 kg, a sample was taken. The catch per unit effort (ind h^{-1}) (CPUE) was also calculated for total catch and each species separately.

The water temperature in the epilimnion was measured from 25 May to 28 June from L. Jyväsjärvi (Temp. 1) and L. Päijänne (Temp. 3) in 1–5 d intervals (Fig. 1). The temperature at the echosounding site (Temp. 2) was measured by data logger in 3-h intervals from 26 April to the end of the study. The air pressure at Tikkakoski (20 km from study site) was measured four times per day by the Finnish Meteorological Institute.

2.4. Statistical analysis

The daily numbers of upstream migrating fish detected by the echosounder, were used for the cross-correlation analysis. All the time series were first differenced ($Y = X_t - X_{(t-1)}$, where X is the measured value at point of time t) to render them stationary and prevent autocorrelations. Cross-correlation functions between the fish count series and the series of the environmental variables were estimated with a time lags of ±5 d. The numbers of upstream migrating fish for the same period as the interval between the trap net examinations were also calculated. Then, a Spearman rank order correlation between the trap net CPUE and the quantity of upstream migrating fish was calculated.

3. Results

Altogether, about 124 000 fish were detected moving upstream past the sample site between 24 April and 28 June in 2001. Some upstream migrating fish were observed instantly after the onset of monitoring, and clear peaks in upstream migration activity were detected as the monitoring progressed (Fig. 3). The first peak was detected on 10 May, followed by a sharp decrease in water temperature which seemed to delay the migration. The highest daily migration of fish was observed on 17 May, when about 11 000 fish passed the sample site.

Temperature in L. Jyväsjärvi and in the channel was generally higher than in L. Päijänne (Fig. 3). A significant cross-correlation (r = 0.40, P < 0.01) was found between the change in the number of upstream migrating fish and the change in temperature the day earlier (time lag 1 d) (Fig. 4). Air pressure changes had no effect on migration activity. Diurnally, migration activity was typically highest at dawn and dusk (Fig. 5).

In all, 13 fish species were caught from Äijälänsalmi channel by the trap net during the study period. The peak of the CPUE of the trap net occurred in the first part of May, the catch consisting mainly of perch and roach (Fig. 6). The upstream migration of ruffe started a few days later. The maximum CPUE of bream and white bream occurred in June. Perch and ruffe observed in the latter part of the study period (after Julian day 151) were small immature specimens, which were probably local fish. The temporal pattern of CPUE resembled the pattern of migration activity (Figs. 3 and 6). The CPUE and the number of fish observed by echosounder, however, did not correlate.

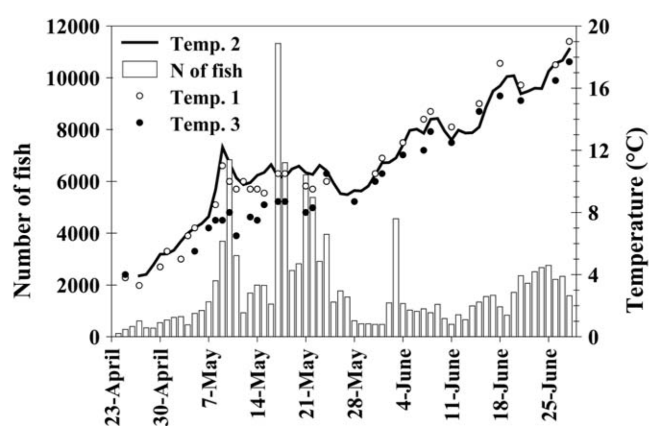

Fig. 3. Daily summary of fish migrating upstream in Äijälänsalmi channel and temperature observations (Temp 1, 2, and 3, refer to Fig. 1).

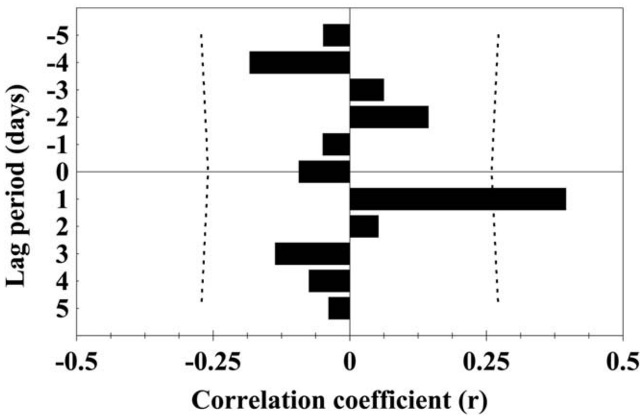

Fig. 4. Cross-correlation analysis between upstream migrating fish and water temperature. Broken lines refer to statistical significance at level of P = 0.05.

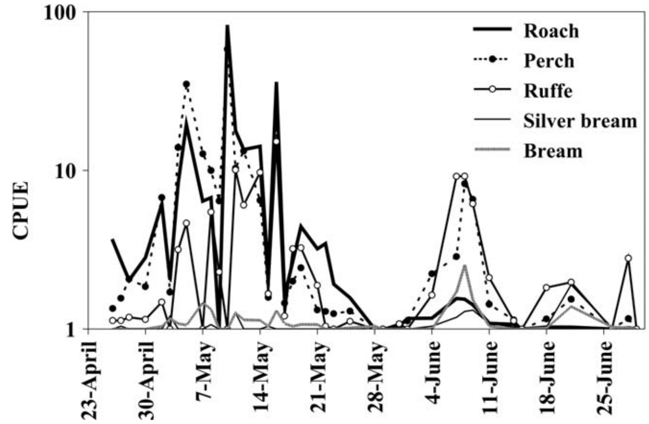

Fig. 6. Catch per unit effort ((n+1) h^{-1}) of trap net for different species in Äijälänsalmi channel. Julian day 113 was 23 April and 176 was 25 June.

The distributions of target strength (TS) and $\log_{10}$(fish length, mm) of the trap net catch had similar patterns in days when the catch was high (Fig. 7). On 10 May, the comparison between the peak of the TS distribution and the peak of the fish length distribution gave the values of –43.5 dB and 135 mm, respectively. On 8 June, the TS distribution was somewhat flatter than on 10 May, and some larger fish were caught by trap net on this day.

4. Discussion

Spawning migrations of bream (Prignon et al., 1998; Molls, 1999; Grift et al., 2001), perch (Craig, 1987), roach (Vøllestad and L'Abee-Lund, 1987; Molls, 1999), ruffe (Lucas and Baras, 2001) and white bream (Prignon et al., 1998; Molls, 1999) were documented. However, an interest in migration of these species is low, because they are usually not economically important. For lake ecosystems, these migrations can be significant. When one considers how to improve L. Jyväsjärvi by intensive fishing for commercially unimportant species, one should consider how removed coarse fish might be replaced by recolonisation from L. Päijänne. All the species observed, migrating from L. Päijänne, are also found in L. Jyväsjärvi. The migrating fish are probably a subpopulation which overwinters in larger L. Päijänne, but migrate to warmer L. Jyväsjärvi to spawn.

Migrations of cyprinids and percids from L. Päijänne to L. Jyväsjärvi are triggered by the temperature difference between these lakes. L. Jyväsjärvi is typically a few degrees

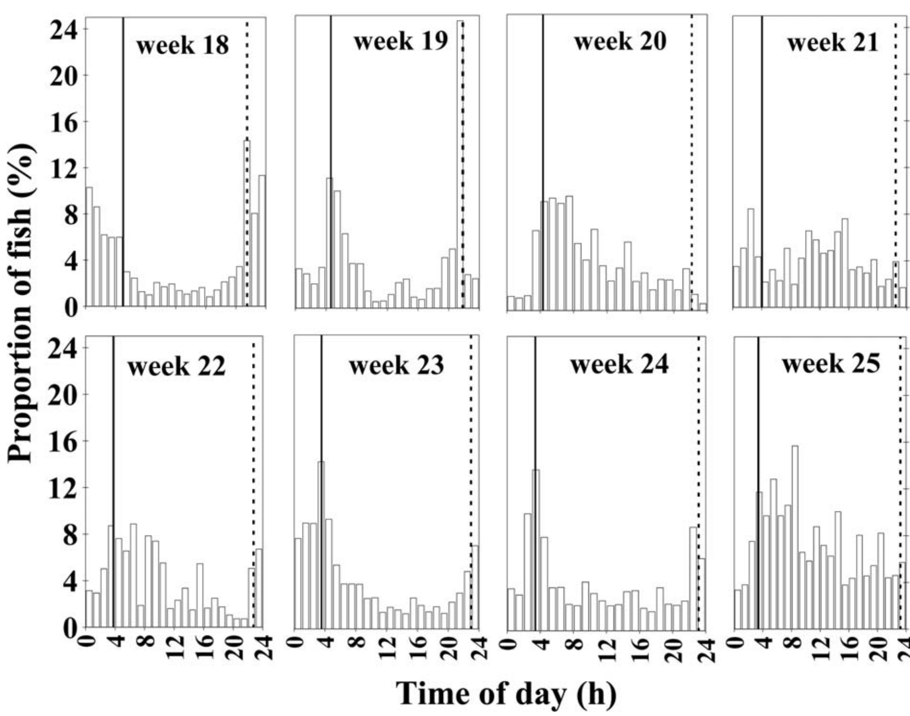

Fig. 5. Daily distribution of the upstream migrating fish in Äijälänsalmi channel. Weekly data pooled, solid line is sunrise and broken line is sunset.

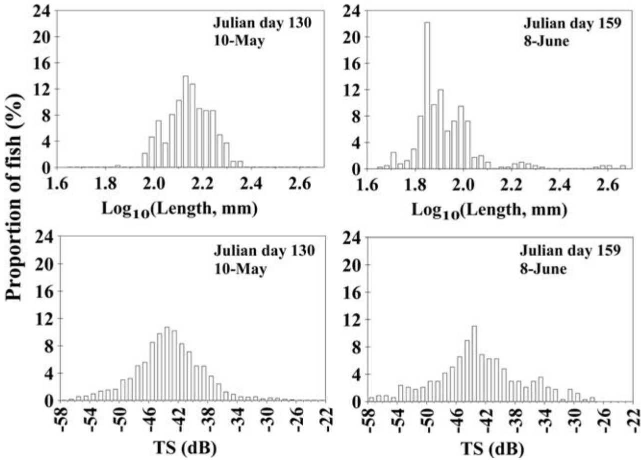

Fig. 7. Target strength (TS) distribution and fish length distribution of trap net catch for 10 May (Julian day 130) and 8 June (Julian day 159).

warmer than L. Päijänne. Temporal changes in temperature seem to regulate the migration activity, as has also been found by Vøllestad and L'Abee-Lund (1987) for roach and Craig (1987) for perch. Between Julian days 127–129, the temperature increased to 4.5 °C, and the largest CPUE was observed on day 130.

In our data, the maximum CPUE of roach, perch, and ruffe in the trap net occurred when water temperature had risen up to about 12 °C. This is higher than the 4–6 °C observed by Vøllestad and L'Abee-Lund (1987). According to the review by Lucas and Baras (2001), the migration temperature trigger for roach varied between 6 and 15 °C in different studies. In the River Ängerån, the spawning migration of perch started when the water temperature was about 10 °C (Berglund, 1978). Hokanson (1977) reported the spawning temperature to be 5–18 °C for perch and 12–18 °C for ruffe. According to Prignon et al. (1998), the spawning migration of white bream and bream was triggered at 10–15 °C. Our data showed that the maximum CPUE of these species occurred at 14–16 °C, generally in agreement with previous studies.

Light rhythm seems to drive the diurnal activity of fish. Lucas et al. (1999) observed a clear diurnal rhythm for adult male chub (*Leuciscus cephalus*) during their spawning migration. Many other species have a diel component to their migration (Lucas and Baras, 2001). We observed the maximum activity near dawn and dusk. In weeks 21 and 22 (Fig. 5), the pattern is not so obvious probably due to low number of migrating fish. In these weeks, much of the catch consisted of non-migrating fish. According to Lucas and Baras (2001), one reason for diurnal migration activity is predation avoidance. Our trap net catch showed that many fish species migrated through the Äijälänsalmi channel. During the first third of the monitoring period, the trap net CPUE and fish counts from echosounder were in good agreement. The poor correlation after 17 May was due to poor and variable catchability of the trap net. This was primarily due to fouling of the trap net. The day after cleaning the trap net, the CPUE was usually higher than before. In addition, during the catch peaks, gear saturation may have decreased catchability. Moreover, different fish species swim in different parts of the channel, avoiding the trap net. Also, decreases in water level and velocity may change the migration route of fish.

According to Kubecka and Duncan (1998b), the relationships between full-side aspect TS (dB) and standard length (SL, mm) of roach and perch were $TS = 26.7 \log_{10}(SL) - 91.0$ and $TS = 23 \log_{10}(SL) - 83$ dB, respectively. In our data, the comparison between the peak of the TS distribution and the peak of the length distribution gives a lower relationship between TS and fish length than the models of Kubecka and Duncan (1998b). There are at least two potential explanations for this difference. First, our beams were directed sloping downward which decreased the TS of our fish. Second, the fish in Äijälänsalmi channel did not necessarily swim perpendicular to the acoustic axis of the beam, in which case, the observed TS would be lower than for full-side aspect (e.g. Love, 1977; Lilja et al., 2000).

Our results confirm that horizontal split-beam echosounding is a suitable method for monitoring upstream migration and activity of fish in a small and slowly flowing channel. In general, the species discrimination is impossible with echosounders in waters, where multiple species are present. Where the fish community is dominated by one species, or an important fish species dominates, species discrimination is less problematic (e.g. Horne, 2000; Romakkaniemi et al., 2000). This study demonstrated that split-beam hydroacoustics gives fish migration information in real time, and allows us to study migration changes in the short term.

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