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The effect of hydropower on fish stocks: comparison between cascade and non-cascade reservoirs

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Abstract Spatial distributions of fish were studied in two types of reservoirs by means of hydroacoustics during the summer. Different patterns of fish distribution were found in non-cascade (Římov, Želivka) and cascade (Kamýk, Slapy, Štěchovice, Vrané) reservoirs. Maximum biomass and density of fish were observed in the tributary area of the non-cascade reservoir. The biomass declined towards the dam area. Average weight of fish showed the opposite trend—maximum average weight was observed in the dam area and declined towards the tributary area. In the cascade reservoirs fish distribution was found to be more complicated but the maximum biomass and density of fish were observed in the dam areas, whereas the tributary areas were nearly fishless. Poor ecohydrological conditions in the tributaries of cascade reservoirs are likely to be responsible for the low abundance of fish in these areas. This was evident in the example of Vrané reservoir which has two major inflows. Low biomass and density of fish were observed in the cold and low oxygen saturated inflowing cascade Vltava River while higher biomass and density were observed in the warm and well oxygen saturated Sázava River inflow. Average weights of fish followed the same trend as in non-cascade reservoirs—the maximum was in the dam area and it declined towards the tributary area. The vertical distribution of fish is driven by the fully developed stratification of temperature and oxygen during the summer season in non-cascade reservoirs. A significantly lower biomass of fish was observed below the thermocline in vertical surveys in both non-cascade and cascade reservoirs. Summer stratification in cascade reservoirs is weakly developed or is not developed at all due to hypolimnetic releases of cold water and short retention times. High transparency suggests lower primary production in cascade reservoirs.

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Hydropower, Flood Control and Water Abstraction: Implications for Fish and Fisheries

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Introduction

Many European rivers were dammed in the past and many papers have dealt with fish communities in reservoirs. Attention was given to studying the fish stocks after the reservoir was built and comparison with their recent state (Gido et al., 2000; Matthews et al., 2004). Several authors have also studied the impact of reservoirs on river fauna (Poddubny & Galat, 1995; Gido et al., 2002a; Falke & Gido, 2006). Patterns of fish species composition in different reservoirs have been reported by Irz et al. (2002); Argillier et al. (2002a); Argillier et al. (2002b); Godinho et al. (1998); Godinho et al. (1997) and the succession of fish communities in reservoirs in Central Europe has been summarized by Kubečka (1993). The majority of reservoirs in Central Europe are eutrophic and their fish communities are dominated by cyprinid species which represent a climax state in reservoir succession. Cascade reservoirs have received very little attention so far, but there are some indications that the patterns of succession are different in such reservoirs due to limitations on the spawning of cyprinids (Hanel & Čihař, 1983; Hrbáček, 1984; Hanel, 1988; Draštík et al., 2004).

Only a few authors have investigated fish communities along a longitudinal profile of the reservoir (Siller et al., 1986; Świerzowski et al., 2000; Vašek et al., 2003, 2004). The aim of this study was to describe the spatial distribution of fish along the longitudinal profiles of reservoirs and compare them within two reservoir groups with different ecohydrology—non-cascade and cascade reservoirs. Vertical distributions of the fish were also studied. This article attempts to answer the questions: (a) is there any common pattern of fish distribution and (b) is the pattern of fish distribution general or does it differ between different kinds of reservoirs?

Materials and methods

Two non-cascade and four cascade reservoirs were chosen for this study of the spatial distribution of fish. Non-cascade reservoirs have no hydropower effect from a dam upstream. Římov and Želivka are canyon-shaped mezo- to eutrophic, non-cascade reservoirs (Fig. 1). Kamýk, Štěchovice and Vrané reservoirs (all <300 ha) and Slapy Reservoir (>1,000 ha; for detailed information see Hrbáček, 1984) are located immediately one after one and form a reservoir cascade on the Vltava River. The characteristics of the reservoirs are shown in Table 1. Inflowing water to all cascade reservoirs is released from hypolimnetic layers and its temperature and saturation by oxygen is low. Considering Vrané reservoir, two rivers flow in to the reservoir: the Vltava River with the hypolimnetic water released from upstream reservoirs and the Sázava River with eutrophic water (Fig. 1). Each reservoir was divided into four separate areas (or five if the reservoir has a second important tributary): tributary, upper, middle and dam areas. Upper, middle and dam areas refer to lentic conditions. Tributary refers partly to lotic conditions in that area.

Routine acoustic surveys were carried out during daytime in late summer 2004—Římov Reservoir 9 August, Želivka Reservoir 15–16 August; cascade reservoirs 31 August–7 September. A Simrad EY500 split-beam echosounder, operating on frequency 120 kHz, was used with two transducers mounted in front of the boat: an elliptical transducer (ES120_4, nominal beam angles 9.1 × 4.3°) beaming horizontally and a circular transducer (ES120_7C, nominal beam 7 × 7°) surveying vertically. The system was calibrated using a tungsten-carbide sphere (Foote et al., 1987). All the reservoirs are canyon-shaped and all their longitudinal profiles were sampled using a zig-zag trajectory where the width of the valley allowed it. All the surveys were divided into transects with different lengths, so that for every reservoir, 50–100 transects with independent estimates of biomass, density and average fish weight were available. Total volumes sampled are given in Table 1. Biomass and density analysis was performed with Sonar 5 post-processing software (Balk & Lindem, 2005). All fish were automatically tracked then manually confirmed. Minimum track length was set to 3 and maximal ping gap set to 1 as the parameters for the tracker. For every fish track, average target strength (ts see Simmonds and Mac Lennan, 2005) was calculated. For calculating density of fish (in individuals ha^{-1}) the sv/ts approach was used with a scaling factor (average ts, see Balk & Lindem, 2005; Simmonds and Mac Lennan, 2005) derived from tracked fish. ts noise thresholds were −60 dB for both the horizontal and vertical surveys. The horizontal surveys covered the first 4 m below the surface (surveyed range of a sidescan was 4–30 m), while the vertical survey covered the rest of the water column to the bottom (>4 m). Fish length was calculated from ts using the relationships of Frouzová et al. (2005) and assuming dorsal aspect in vertical records and random

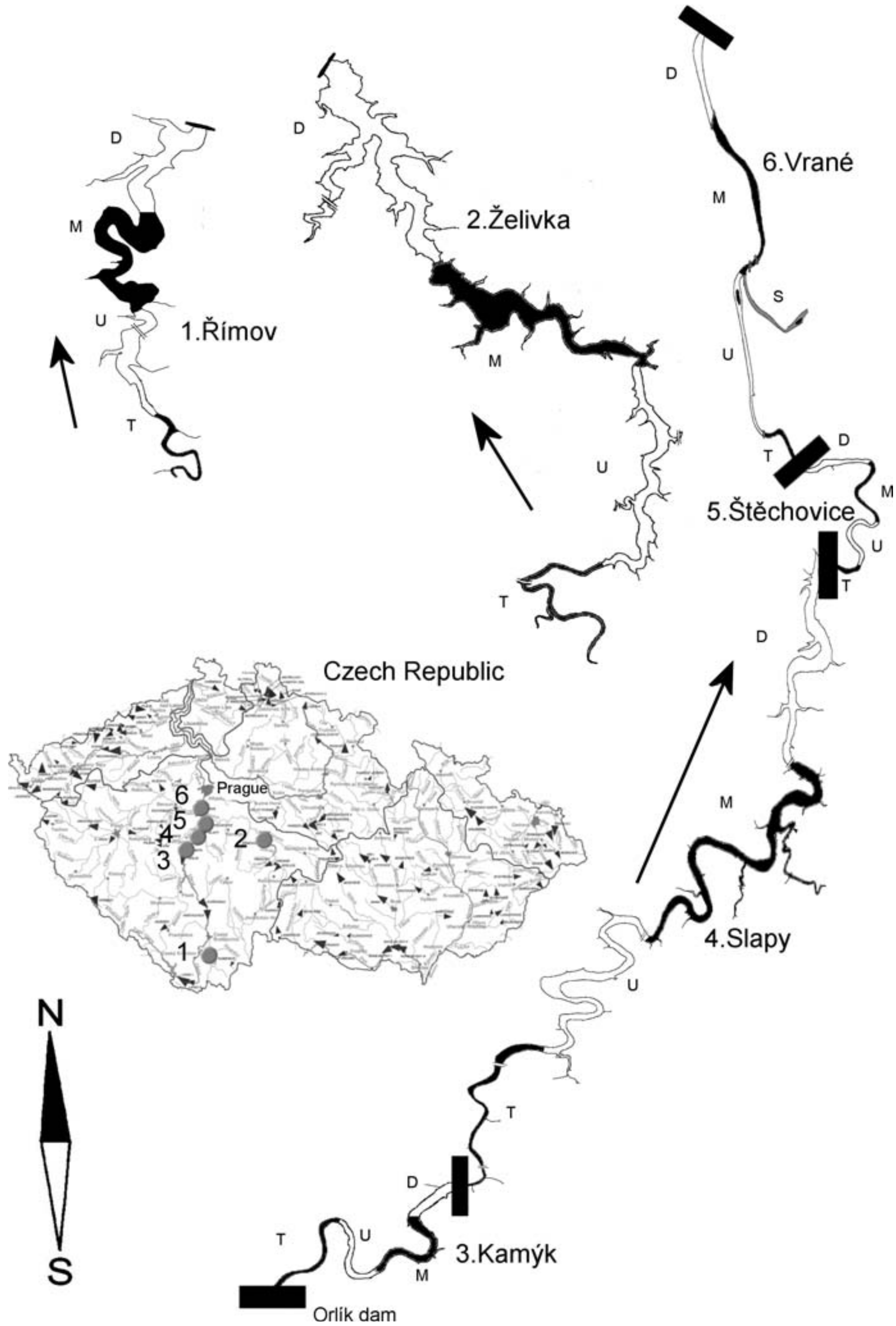

Fig. 1 Locations of the reservoirs studied and their sequence in a cascade. Black and white colours distinguish between different localities (T—tributary, U—upper, M—middle and D—dam area) in each reservoir; grey represents the Sázava arm (S) in Vrané Reservoir. Black arrows indicate the direction of flow in the reservoir. Be aware of different scale—the size of each reservoir is shown in Table 1

distribution of fish in the horizontal plane (Kubečka et al., 1994). Fish lengths were converted to weights using length–weight relationships (fish from the Římov reservoir, unpublished data) and the biomass was obtained by multiplying average weight and density. Summer stratification was measured by a calibrated ISY 556 MPS probe in at least three places along the longitudinal axis of each reservoir. Transparency was measured by Secchi disk at the same places. Differences in the spatial distribution of fish along the longitudinal axes of the reservoirs were tested by one-way ANOVA and comparison of vertical distributions of fish was tested by two-way ANOVA in STATISTICA software, version 6. Tukey HSD post hoc comparisons were used for detailed identification of significantly different localities.

Table 1 The basic characteristics of non-cascade and cascade reservoirs studied in the Czech Republic—year of filling, area, volume, maximum depth, average retention time (RT), summer average of chlorophyll *a* (Chl *a*), sampled volume (Samp. vol.) and maximal daily water level fluctuation (WLF)

Reservoir	Year of filling	Area (ha)	Volume (mil. m^3)	Max. depth (m)	RT (days)	Chl *a* ($\mu g\ l^{-1}$)	Samp. vol. (mil. m^3)	mWLF (m)
Římov	1978	210	34.5	43.9	130.0	45.0	5.4	0.1
Želivka	1976	1,432	246.0	55.7	424.0	10.8	34.5	0.1
Kamýk	1963	195	12.1	14.5	1.8	18.0	1.2	1.0
Slapy	1955	1,392	269.3	58.0	38.5	30.0	23.6	0.5
Štěchovice	1945	115	11.2	20.6	1.5	3.5	0.9	4.0
Vrané	1935	251	11.1	10.2	1.2	40.0	1.0	0.5

Results

Non-cascade reservoirs

The spatial distribution of fish in both non-cascade reservoirs showed a clear pattern. Estimates of mean fish biomass and density along the reservoirs were significantly different among the areas examined in both the Římov reservoir (Fig. 2a, b; biomass $F = 3.94$, d.f. = 3, $P = 0.01$; density $F = 33.27$, d.f. = 3, $P < 10^{-6}$) and the Želivka reservoir (Fig. 3a, b; biomass $F = 4.55$, d.f. = 3, $P = 0.01$; density $F = 19.13$, d.f. = 3, $P < 10^{-6}$). The highest fish density and biomass revealed by the horizontal surveys was observed in the tributary area of both reservoirs. Tributary area were significantly different from upper ($P = 0.045$) and middle ($P = 0.016$) areas in fish biomass and from upper, middle and dam areas in fish density (all $P = 0.02$). Fish biomasses and densities estimated by vertical surveys in the non-cascade reservoirs seem to be of little significance because only small numbers of fish were observed in the deeper layers (below the thermocline, Table 2) of a few transects. Biomass estimates were higher in the horizontal surveys than in the vertical surveys of both non-cascade reservoirs (Želivka $F = 10.80$, d.f. = 1, $P = 0.001$; Římov $F = 45.32$, d.f. = 1, $P < 10^{-6}$). Fish density was not significantly different but it was slightly higher in the horizontal survey than in the vertical survey. The size of the fish shows a clear pattern in Římov reservoir (Fig. 4). The estimate of the average fish weight varied significantly among the four areas ($F = 10.83$, d.f. = 3,

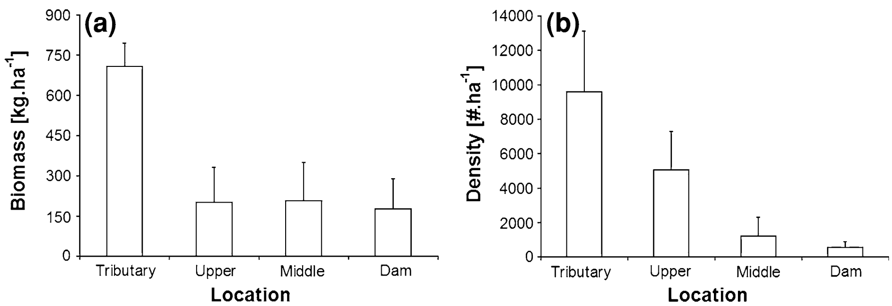

Fig. 2 Observed mean biomass (**a**) and density (**b**) of fish in the non-cascade reservoir Římov revealed by horizontal acoustics. Significant differences were found between areas. Error bars represents standard deviations (SD)

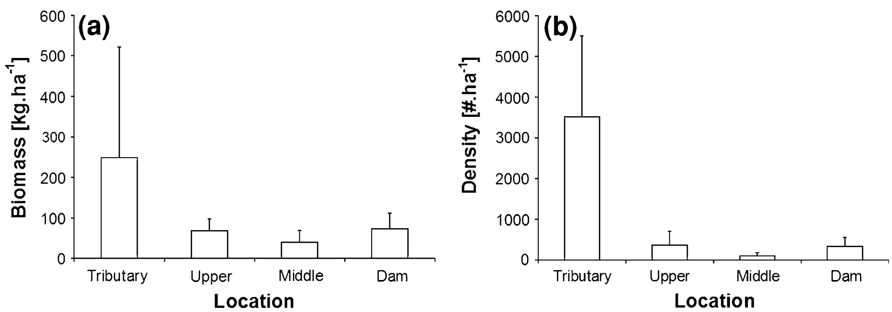

Fig. 3 Observed mean biomass (**a**) and density (**b**) of fish in the non-cascade reservoir Želivka revealed by horizontal acoustics. Significant differences were found between areas. Error bars represents standard deviations (SD)

Table 2 Average biomass and density of fish revealed by horizontal and vertical acoustic surveys of the reservoirs listed

	Horizontal				Vertical			
	Biomass		Density		Biomass		Density	
	Average	SD	Average	SD	Average	SD	Average	SD
Želivka	110.3	148.9	849	1,437	26.0	93.1	698	885
Římov	216.3	162.3	2,186	2,673	0.2	0.3	2,520	3,141
Kamýk	214.8	601.2	449	487	1.0	2.9	330	467
Slapy	194.4	340.3	3,100	6,748	5.7	21.6	2,343	6,304
Štěchovice	39.9	40.5	1,323	1,516	2.4	8.4	216	356
Vrané	37.5	94.6	1,293	2,433	0.2	1.1	143	443

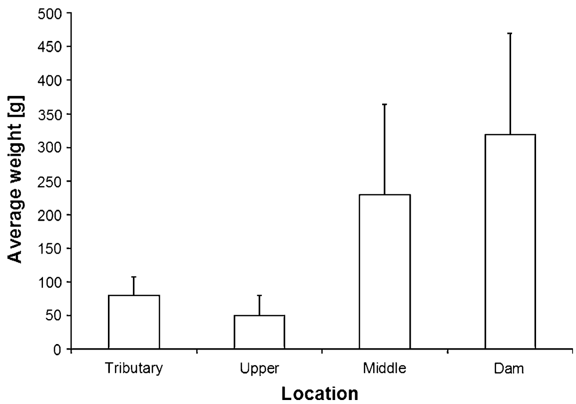

Fig. 4 Mean average weight of fish in different areas of Římov reservoir. Significant differences were found between areas. Error bars represents standard deviations (SD)

$P < 10^{-6}$). The estimated average weight was highest in the dam area and lowest in the tributary. The dam area differed significantly from tributary and upper areas ($P = 0.037$, $P = 0.003$ reps.) and the middle area differed from the upper area ($P = 0.02$). Estimates of the average weight did not differ significantly among four areas in Želivka reservoir ($P > 0.05$) but fish in the tributary area were of slightly smaller average weight than fish in other parts of the reservoir. The high biomass of fish in the tributary areas of these reservoirs is formed by high densities of small fish. Both non-cascade reservoirs were fully stratified in terms of temperature as well as oxygen. The thermocline was developed at a depth of 4 m (Fig. 5). Water transparency was 2 m close to the dam.

Cascade reservoirs

Kamýk and Štěchovice reservoirs are small, shallow cascade reservoirs (area < 200 ha). Kamýk Reservoir is located immediately below the large Orlík Reservoir (2,733 ha, volume 717 mm^3, depth 72 m). Fish mainly inhabited the dam area, where several aggregations of large fish occurred. The horizontal survey revealed most fish biomass ($F = 4.53$, d.f. = 3, $P = 0.01$) and density ($F = 6.11$, d.f. = 3, $P = 0.004$) in the dam area (Fig. 6a, b). Fish biomass and density in the dam area was significantly different from the tributary, upper and middle areas (biomass: $P = 0.04$, $P = 0.04$, $P = 0.02$ resp.; density: $P = 0.01$, $P = 0.03$, $P = 0.01$ resp.). Very few

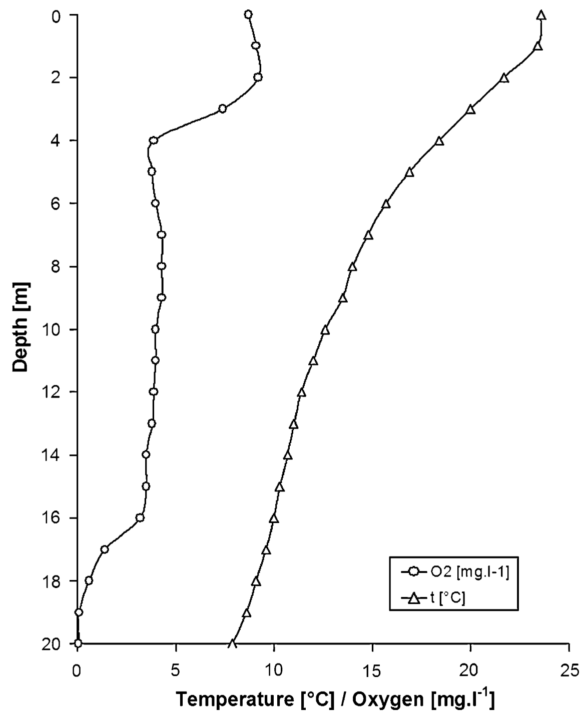

Fig. 5 Summer stratification of temperature and oxygen in the dam area of Římov reservoir

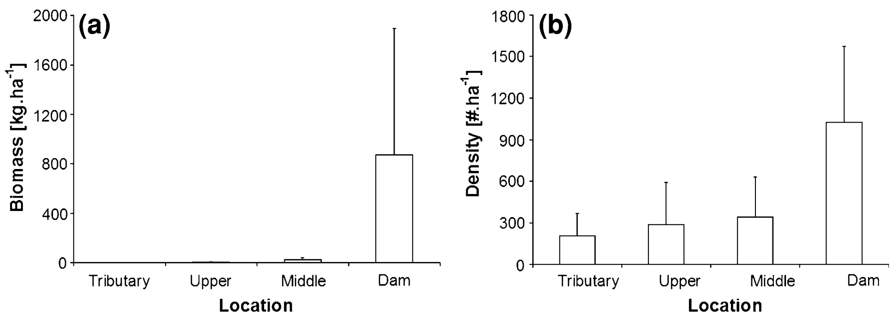

Fig. 6 Observed mean biomass (**a**) and density (**b**) of fish in the cascade Kamýk Reservoir revealed by horizontal acoustics. Significant differences were found between areas. Error bars represents standard deviations (SD)

fish were recorded in deeper layers by the vertical beaming (Table 2); most of them again in the dam area. The biomasses estimated by horizontal and vertical beaming were significantly different ($F = 4.33$, d.f. = 1, $P = 0.04$). The average weight of fish was also highest in the dam area (Fig. 7, $F = 4.06$, d.f. = 3, $P = 0.02$). The estimated average fish weight in the dam area was significantly different from the tributary and upper areas ($P = 0.03$ for both). The reservoir was not stratified (Fig. 8a) and transparency was 3.5 m.

Fish distribution in Štěchovice Reservoir did not show any clear pattern. Estimates of mean biomass and density were not significantly different along the longitudinal axis (Fig. 9a, b; $P > 0.05$). Estimates of biomass ($F = 38.49$, d.f. = 1, $P < 10^{-6}$) and density ($F = 21.6$, d.f. = 1, $P < 10^{-6}$) were significantly higher for the horizontal survey than for the vertical survey (Table 2). Summer stratification had not developed (Fig. 8b) and transparency was 3.5 m.

Slapy Reservoir is a 42 km long, mezo- to eutrophic reservoir which is situated in the middle

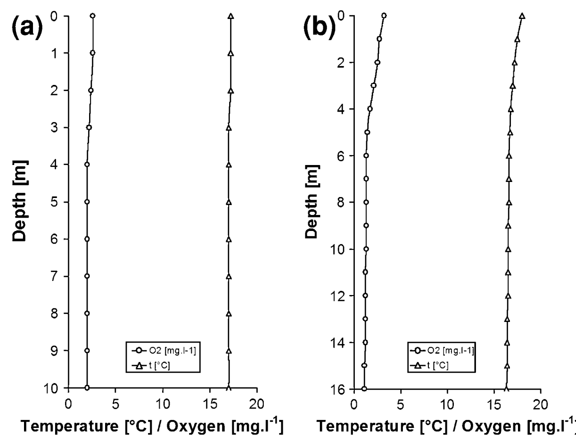

Fig. 8 Temperature and dissolved oxygen profiles in the small cascade Kamýk (**a**) and Štěchovice (**b**) reservoirs. Summer stratification was not developed.

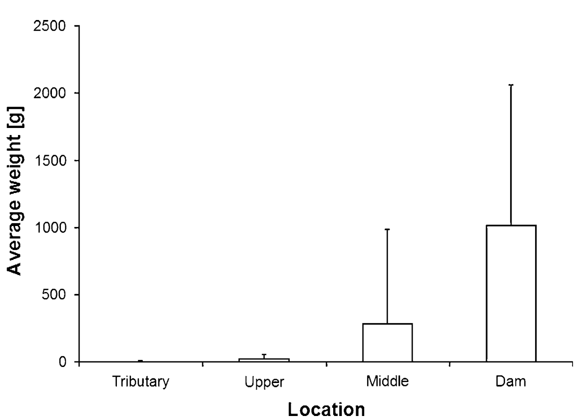

Fig. 7 Mean average weights of fish in different areas of Kamýk Reservoir. Significant differences were found between areas. Error bars represents standard deviations (SD)

of the Vltava river cascade. The highest fish biomass ($F = 6.26$, d.f. = 3, $P = 0.001$) and density ($F = 5.64$, d.f. = 3, $P = 0.002$) estimates were found in the dam area (Fig. 10a, b). Fish biomass in the dam area was significantly different from the tributary, upper and middle areas ($P = 0.02$, $P = 0.004$, 0.006 resp.). Fish density in dam area was significantly different from upper and middle area ($P = 0.01$ for both). Fish biomass in the horizontal survey was higher than that in the vertical survey ($F = 21.05$, d.f. = 1, $P < 10^{-6}$). The reservoir was not stratified in the tributary area, where the influence of hypolimnetic water from Orlík and Kamýk reservoirs is apparent, but other parts were stratified in terms of temperature and oxygen concentration with a thermocline at a depth of 8 m (Fig. 11). Transparency was high in the tributary area (3.6 m), lower in the dam area (2.6 m) but lowest just below the plunging point (1.1 m).

Vrané Reservoir is a small, shallow cascade reservoir with two tributaries (Fig. 1). The horizontal

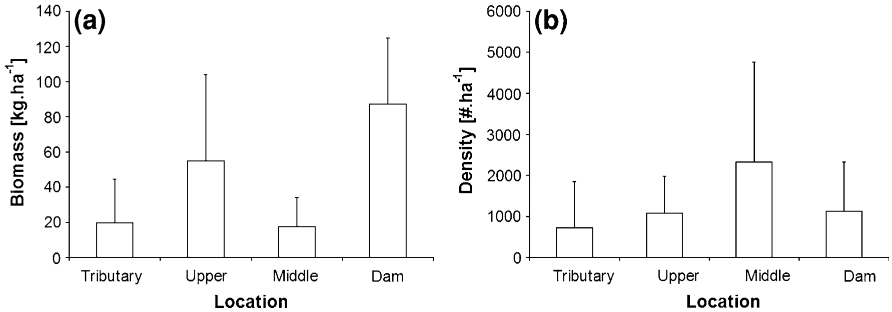

Fig. 9 Observed mean biomass (**a**) and density (**b**) of fish in the cascade Štěchovice Reservoir revealed by horizontal acoustics. No significant differences were found between areas. Error bars represents standard deviations (SD)

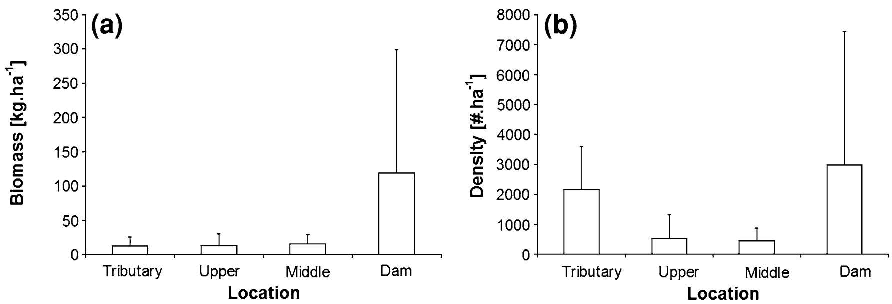

Fig. 10 Observed mean biomass (**a**) and density (**b**) of fish in the cascade Slapy Reservoir revealed by horizontal acoustics. Significant differences were found between areas. Error bars represents standard deviations (SD)

survey revealed the highest fish biomass estimate in the Sázava arm and in the dam area and low biomass was observed in the tributary and upper area—the Vltava arm (Fig. 12a; $F = 10.53$, d.f. = 4, $P < 10^{-6}$). Fish biomass in Sázava arm was different from all other areas in the reservoir: tributary, upper, middle and dam ($P = 0.01$, $P = 0.001$, $P = 0.0001$, $P = 0.01$ resp.). The density of fish was also high in the Sázava arm and low in other parts of the reservoir including the dam area (Fig. 12b; $F = 3.68$, d.f. = 4, $P = 0.01$). Fish density in the Sázava arm was significantly different from the tributary, upper, middle and dam areas ($P = 0.02$, $P = 0.04$, $P = 0.02$, $P = 0.02$ resp.). Fish distribution in the vertical survey did not vary along the longitudinal axis of the reservoir ($P > 0.05$). Fish biomass and density observed by the horizontal survey was significantly higher than the density and biomass from the vertical survey (biomass $F = 23.95$, d.f. = 1, $P < 10^{-6}$; density $F = 42.10$, d.f. = 1, $P < 10^{-6}$). The average weight of fish was high in the dam area and Sázava arm and low in the tributary and upper part (Fig. 13; $F = 4.93$, d.f. = 3, $P = 0.002$). The estimated average fish weight in the dam area was significantly different from the tributary, upper and middle areas ($P = 0.045$, $P = 0.006$, $P = 0.035$ resp.). Vrané Reservoir was stratified in the dam area and Sázava arm (Fig. 14). The transparency of the water was low (0.9 m, 0.45 m resp.) while the water in the Vltava arm was not stratified (Fig. 14) and its transparency was higher (3 m).

Discussion

This study reveals a clear pattern of fish distribution in non-cascade reservoirs. Estimates of fish biomass and density were highest in tributary areas and decreased (though not monotonically) towards the dam areas. A same distribution pattern has been reported by many other authors from European and American reservoirs (Vondracek et al., 1989; Fernando and Holčík, 1991; Brosse et al., 1999; Świerzowski et al., 2000; Gido et al. 2002b; Vašek et al., 2003, 2004; Matthews et al., 2004) sampled using hydroacoustics, gillnets or other fishing gear. Tributary areas are usually very eutrophic in summer and trophic level declines towards the dam (Lind et al., 1993; Straškraba, 1998) so this area is considered a very important part of the reservoir for two reasons: it represents the most productive part of the reservoir on a longitudinal trophic gradient, and it forms an important area for fish reproduction. Strong longitudinal (tributary to dam) gradients of total phosphorus, chlorophyll a and zooplankton density

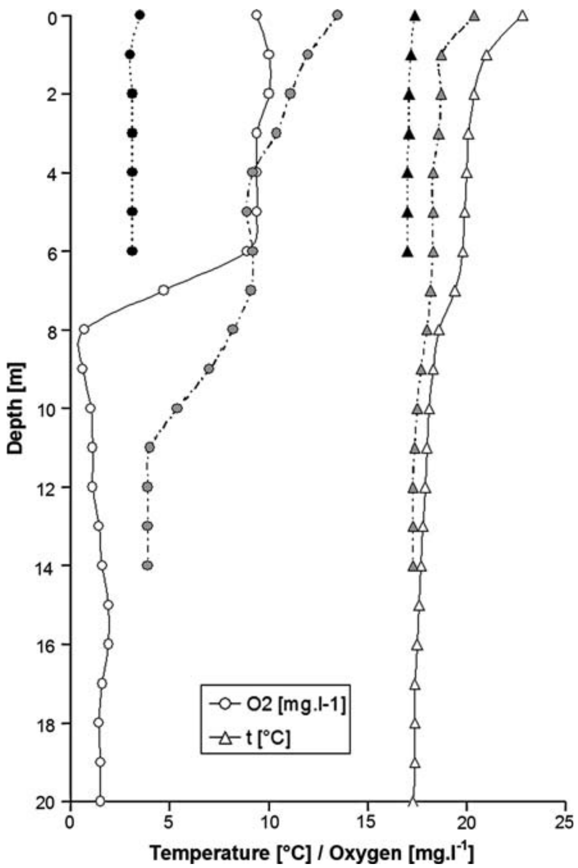

Fig. 11 Temperature and dissolved oxygen profiles in the cascade Slapy Reservoir. The reservoir was stratified in the upper (grey), middle and dam (white) areas and was not stratified in the tributary area (black)

are common phenomena in non-cascade reservoirs (Nakashima and Leggett, 1975; Fernandez-Rosado et al., 1994; Hejzlar & Vyhnálek, 1998; Seďa and Deveter, 2000; Fernandez-Rosado & Lucena 2001). Fish distribution reflects these gradients as described by the results of this study as well as by other authors (Siller et al., 1986; Brosse et al., 1999; Gido et al., 2002b; Matthews et al., 2004; Vašek et al., 2004). A positive correlation between fish density and the amount of total phosphorus or chlorophyll a has been observed in some Scandinavian lakes (Jeppesen et al., 2000; Olin et al., 2002) and German lakes (Mehner et al., 2005). Lakes with high concentrations of total phosphorus have a high biomass of fish and the proportion of cyprinids is also high. It is not possible to distinguish fish species by acoustics but Czech non-cascade reservoirs are dominated by cyprinids (mainly bream (*Abramis brama* (L.)), roach (*Rutilus rutilus* (L.)) and bleak (*Alburnus alburnus* (L.))—Vašek et al., 2004; Prchalová et al., 2006). High density and biomass of fish in the tributary area is composed of a higher proportion of small fish, probably juveniles. Vašek et al. (2004, 2006) observed a higher proportion of young-of-year (YOY) fish in the tributary of Římov reservoir. In the concept of riverine origin of fish in reservoirs (Fernando & Holčík, 1991; Holčík, 1998) the tributary zone serves as an important spawning area for reservoir fish (Hladík & Kubečka, 2003). Vertical

Fig. 13 Mean average weight of fish in different areas of Vrané Reservoir. Significant differences were found between areas. Error bars represents standard deviations (SD)

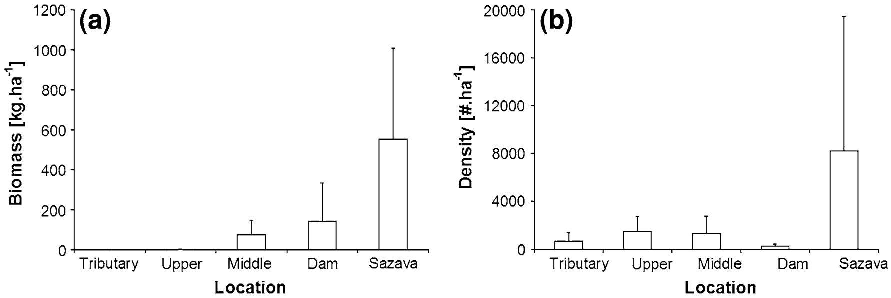

Fig. 12 Observed mean biomass (**a**) and density (**b**) of fish in the cascade Vrané Reservoir revealed by horizontal acoustics. Significant differences were found between areas. Sazava is the 2nd tributary (see in text). Error bars represents standard deviations (SD)

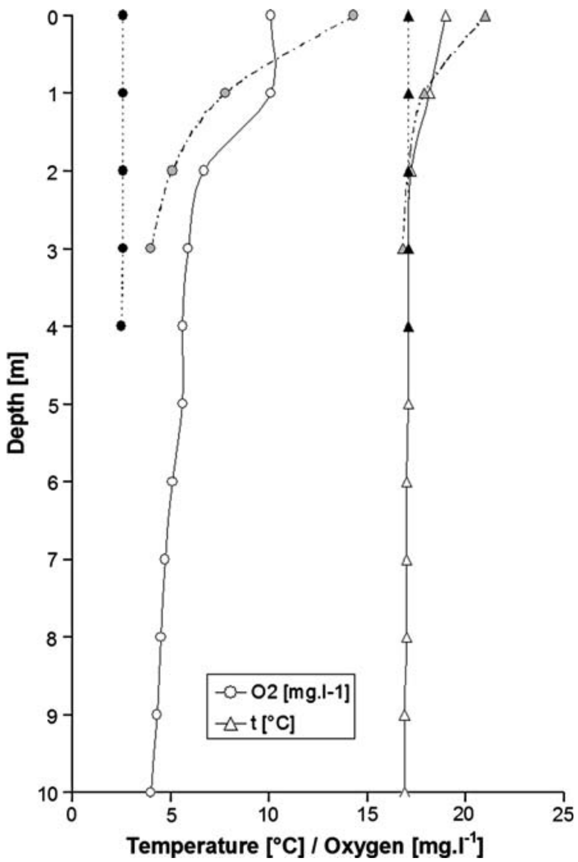

Fig. 14 Temperature and dissolved oxygen profiles in the cascade Vrané Reservoir. The reservoir was stratified in Sázava river arm (grey) and dam area (white) but was not stratified in Vltava river arm (black)

distribution also follows a clear pattern due to strong summer stratification. The majority of the fish biomass was located in surface layers above the thermocline (Schael et al., 1995; Kubečka & Wittingerová, 1998; Vašek et al., 2004). It seems that fish are very unwilling to swim into the colder, less oxygen saturated water below the thermocline.

The first common feature of fish distribution in the Vltava river cascade reservoirs is that the tributary usually appears to be little inhabited by fish compared to the high biomasses and densities in the tributaries of non-cascade reservoirs. The main reason for the low biomass and density of fish seems to be the quality of water flowing into the reservoir. In the Vltava River cascade the reservoirs are situated one immediately after another and the water that is discharged into a lower reservoir usually comes from the deep layers of the reservoir above, through the turbines (Fig. 1). This hypolimnetic inflow is cold and very poorly saturated with oxygen in summer which is very opposite to the tributary of non-cascade reservoirs (Figs. 8, 11 and Hrbáček & Straškraba, 1966; Hrbáček, 1984). Fish distribution in Vrané Reservoir fully supports this hypothesis. Two comparable rivers (in terms of average discharge) flow into this reservoir but they differ in temperature and concentration of oxygen. A low biomass and density of fish was observed in the cold and poorly oxygen saturated Vltava arm. On the other hand, a high biomass and density were observed in the warm and well oxygen saturated Sázava arm as is common in the tributary of non-cascade reservoirs. Also, fish biomass and density remain low to the confluent of Vltava and Sázava rivers. Releasing of cold and low oxygen saturated water from the hypolimnium of the upstream reservoir lowers the fish biomass and density in cascade reservoirs. Mass fish kills were even experienced during the summer caused by oxygen deficits. Oxidizing of released water from an upstream reservoir might be helpful especially in summer season.

A second shared feature of fish distribution in the Vltava River cascade reservoirs is the high biomass and density found in dam areas. This biomass was formed mainly of adult fish (mean average weight >400 g), especially in Kamýk and Vrané reservoirs. Most of these big adult individuals are unlikely to be of autochthonous origin. Many carp (*Cyprinus carpio*) have been flushed into the reservoirs from fish ponds in the catchment during an extreme flooding event in 2002 (Rutkayová et al., 2006) or come from a regular stocking programme of the Czech Fishing Union (Draštík et al., 2004) and were using the warmest near-surface layers of the dam area. In cascade reservoirs with low reproduction of cyprinid fish (Draštík et al., 2004), the input of fish by flooding may have a significant impact on increasing standing stock. In non-cascade reservoirs even extreme flooding does not necessarily have a significant impact of on the total fish stock (Vašek et al., 2004) or even on fish composition (Gido et al., 2000; Kubečka et al., 2004).

The development and stability of summer stratification was examined by Straškraba & Hocking (2002) who found that retention time (RT) has an important influence on hydrodynamic conditions in a reservoir and on the development and stability of summer stratification up to RT = 200 days. The shorter the RT is, the weaker the stratification that develops. Cascade reservoirs have very short RT compared to non-cascade reservoirs. The same authors state that temperature stratification is also very sensitive to the inflow temperature and outlet depth. Cascade reservoirs usually have cold inflows of water released from the hypolimnetic layers of an upstream reservoir. Thus, summer stratification is unable to develop in small cascade reservoirs (Kamýk Reservoir and Štěchovice Reservoir) or is developed very weakly (Vrané Reservoir) and the temperature and concentration of oxygen is low in whole reservoir. Only if a reservoir is big enough does the cold water from the tributary flow into the deeper layers of the reservoir and stratification can develop in summer (Slapy Reservoir) but the depth of the thermocline lies deeper than is observed in non-cascade reservoirs. Comparison of the results from horizontal and vertical surveys in Slapy Reservoir shows that the fish stay close to the surface even if temperature and concentration of oxygen are not limiting. Deep layers of both cascade and non-cascade reservoirs seem not to be attractive to fish during summer, except for bathypelagic percid fry (Čech et al., 2005, 2007; Čech & Kubečka, 2006).

Water level fluctuations caused by hydro-peaking is considered to be one of a few parameters which influences fish distribution and the success of fish reproduction and water level fluctuations have become a central theme of ecohydrology in rivers (Baras & Lucas, 2001). In reservoir limnology, seasonal water level fluctuation and its impact on reservoir biota were usually considered (Ploskey, 1986; Willis, 1986) but, in the long run, reduced reproduction could result in reduced abundance and biomass. Comparison of actual values of average biomass in Table 2 shows that this may not always be the case. The detrimental effect of the reservoir cascade was probably overshadowed by the flood event in 2002 (Brazdil et al., 2006) which occurs once in 500 years.

Conclusions

Major differences were found in the spatial distributions of fish between cascade and non-cascade reservoirs. Fish biomass and density is highest in the tributary area and declines towards the dam in non-cascade reservoirs. Average fish weight follows the opposite pattern—low in the tributary and higher towards the dam. Non-cascade reservoirs are fully stratified in summer, in terms of temperature and concentration of dissolved oxygen, and the majority of fish are located in the epilimnium and only a small part can be observed in the hypolimnium.

Fish biomass is highest in the dam area in cascade reservoirs while the tributary area is nearly fishless and the average fish weight follows the same pattern as in non-cascade reservoirs. Although summer stratification is weakly developed, the majority of fish in these reservoirs are located in layers close to the surface. If a cascade reservoir has another important inflow, with good ecohydrological conditions, fish show a strong affinity to this part.

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