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Spawning migration of brown trout, *Salmo trutta* in the Morávka reservoir

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A b s t r a c t. The spawning migration from Moravka reservoir to the Moravka river tributary of brown trout in autumn (October – November) lasted 22, 24, and 27 days respectively in the seasons 2002–2004. In 2002, 187 fish were trapped, while the number of trapped spawners increased to 447 in 2003 and 2230 in 2004. Spawning males were significantly longer than females ($P<0.01$). In 2002, more females than males ($P<0.05$) migrated. The sex-ratio in the following seasons did not significantly differ from 1:1. Spawning migration started under the conditions of increasing water levels and the water temperature decreased below 8°C in the reservoir. The peak of spawning, in all three seasons, took place between 28 October and 3 November, and the river water temperature varied from 6 to 8°C. The spawning in 2002 was more nocturnal (between 8:00 p.m. to 6:00 a.m.) than diurnal ($P<0.01$) and the diel activity showed the multimodal distribution. There were no large or significant differences between the diurnal and nocturnal migrations in 2003 and 2004. Single environmental variables and their interaction were significantly related to the spawning migration only in 2003 and 2004 ($P<0.001$).

Key words: reproductive migration, tributary, trap, diel activity, environmental factors

Introduction

Brown trout (*Salmo trutta)*, similarly to other species of Salmonidae, undertakes spawning migrations during its reproductive cycles. In natural river systems, these species migrate to smaller tributaries of the main flow (L i b o s v á r s k ý 1967, 1976, O v i d i o et al. 1998, A a r e s t r u p & J e p s e n 1998, M e y e r 2001, O v i d i o et al. 2004). In lakes or artificial water reservoirs the salmon species and grayling migrate, at the time of their reproduction, to bigger tributaries where their spawning takes place (S a k o w i c z 1963, S a k o w i c z & S z c z e r b o w s k i 1965, K r i s t i a n s e n & D ø v i n g 1996, B l a n c h f i e l d & R i d g w a y 1997, B a r i l & M a n g a n 2002, C a r l s s o n et al. 2004). Physical parameters (water temperature, flow in the tributary, precipitation, etc.) function as starting mechanisms for reproduction cycles and they influence the duration of spawning migrations (L i b o s v á r s k ý 1974, A r n e k l e i v & K r a a b ø l 1996, J o n s s o n 1991, J o n s s o n & J o n s s o n 2002, R u s t a d b a k k e n et al. 2004). Many authors have studied spawning migrations using a radio-telemetry (G e r l i e r & R o c h e 1998, O v i d i o et al. 2002, O v i d i o & P h i l i p p a r t 2002, M o n e t & S o a r e s 2001, A a r e s t r u p et al. 2002, K n o u f t & S p o l i t a 2002).

This study deals with the duration of the trout spawning migration under the conditions existing in the Morávka reservoir, which has been subjected to ichthyological research for a

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number of years (Fig. 1). Species from the salmon family (brown trout, steelhead, and brook charr), together with grayling were the important species in this reservoir in the past. Brown trout and grayling have maintained their dominant position (biomass) within the ichthyocenosis for thirty years since the first fill up of the reservoir in 1966 (L o j k á s e k 1996).

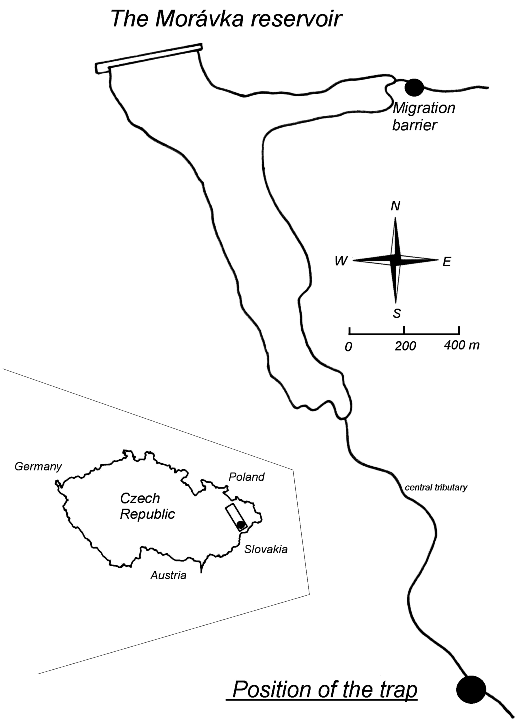

Fig. 1. Map of the study area and the trap position.

Study Area

The Morávka valley reservoir was built on the river of the same name, at river km 18.4, in the period 1960–1964. The geographic coordinates are: N = 49°35“, E = 18°25“. The reservoir catchment covers an area of 63.3 km^2 and is situated from 500 to 1 201 metres above the sea level. The top of the dam, 396 m long, is 517 metres above the sea level and the height of the dam is 39 m. The maximum volume of the reservoir is 11.3 million cubic metres of water. When the reservoir is full its volume is 0.795 km^2, the length of the shore line is 5 km, and the length of the flooded area is 2.8 km. The average width is 200 m and the maximum depth reaches 37.3 m. The theoretical time of retention is 69 days, under the assumption of the average water flow at the dam profile, which is 0.8 m^3.s^{-1} (Fig. 1). Main sources are the flow of Morávka and the smaller tributaries of Slavíč and Skalka, which have the character of mountain creeks (V l č e k 1984). The forest cover of the reservoir catchment area is about 90% and the area of agricultural land is 5.4%. The reservoir catchment has the highest precipitation in the Czech Republic, 1 400 mm a year on average. Water from the reservoir is utilised for drinking.

The first information about the ichthyofauna in the flooded area was provided by F r a n k (1962). Morávka River had been managed as a trout territory before the reservoir was filled

Table 1. Brown trout and grayling plant project releasing the fishes to the Morávka reservoir during five years.

Year	Species	Total length of fish (cm)	No. individuals
2000	*Salmo trutta*	12–15	5500
	Salmo trutta	3.5	60000
	Thymallus thymallus	17	8400
	Thymallus thymallus	9.5	15000
2001	*Salmo trutta*	15	1000
	Thymallus thymallus	9–11	5500
2002	*Salmo trutta*	12–14	6600
	Thymallus thymallus	6	15000
	Thymallus thymallus	11	12200
2003	*Salmo trutta*	3	50000
	Salmo trutta	7–20	2200
	Thymallus thymallus	8	50000
2004	*Salmo trutta*	8–25	1800
	Thymallus thymallus	15–20	6000

up. There were the brown trout *(Salmo trutta),* grayling *(Thymallus thymallus),* common minnow *(Phoxinus phoxinus),* stone loach *(Barbatula barbatula),* common sculpin *(Cottus gobio)* and Carpathian sculpin *(Cottus poecilopus)* in the flooded area. The ichthyological research of the reservoir started in 1982 and continued until the reservoir was drained in 1996 (L o j k á s e k 1996). The reservoir was refilled after the dam reconstruction in March 2000. Since then an intensive stocking by brown trout and grayling has been organised (Table 1). On average, there are 75.3 ind'.ha^{-1} of brown trout of the total length 100–200 mm introduced (age 1+ - 2+).

Material and Methods

Migrating fish were trapped in a trap box of a special construction. The box was placed in the main reservoir tributary, about 700 m from its inlet. The river bed was dammed in that place and the trap was positioned in such a way that the migrating fish could not get over the dammed profile outside the trap box, through which the main flow occurred. There was a concrete slab with fittings for cardia or wooden planks, which managed the water flow through the box, at the bottom of the river bed situated across the place where in which the trap box was installed. The width of the flow profile in the trapping place was 12.7 m. The size of the cardia was 1 x 1.5 m and the gaps between individual rods in the cardia were 0.02 m wide. The laid trap box had the shape of a block 3.6 m long, 1.17 m wide and 1 m high (Fig. 2b).

The trap was inspected at alternate hours during the entire period of installation. The number of trapped individuals and their sex were recorded. Standard length (Sl ± 1 mm) and weight (W ± 1 g) of randomly selected individuals were measured. Water temperature (± 0.1°C) was monitored in the trapping place at two hourly intervals. Data about the water flow in the trapping place, water temperature in the reservoir and precipitation were received from the managing office of the flow manager in Povodí Odry, s.p. (the state company Water Catchment of the River Odra).

a) b)

Fig. 2. The constructed trap was used for the monitoring of spawning migration of brown trout in the tributary of Morávka reservoir, a) the concrete board on the stream bottom, b) the assembled trap.

The chi-square test was used for the assessment of the sex ratio of the trapped fish. The parametric T-test was used for the analysis of fish lengths. Differences between the day hours and night activities were found with the Wilcoxon test. Impacts of environmental factors on the duration of the brown trout spawning migration were analysed by multiple regression. All values given are the Mean ± SE Standard Error.

Results

Chronology of the spawning migration

The spawning migrations were monitored for their whole durations. The monitoring of the spawning trout migration in 2002 took place from 18 October to 8 November, i.e. for 22 days, when 187 fish were trapped. The spawning trout migration had a single day peak in that season. The number of trout migrating reached a peak on 28 October, when 45 fish (24.1 %) were trapped (see Fig. 3a). In 2003, the trap box was installed from 20 October to 12 November and 447 fish were trapped during these 24 days. The peak of the trout migration lasted from 1 to 3 November in that year, when 225 individuals (50.3%) were trapped. Similar results were recorded also in 2004, when 2 230 fish in total were trapped between 15 October and 10 November (Fig. 3c). Most of the fish (30%) migrated on 1 November (668 individuals). The spawning trout migration corresponds, in all these years, with a single mode distribution (Kolmogorov-Smirnov, $P<0.05$). We assume that the increasing number of migrating spawners during the period was the result of the intensive trout releases into the reservoir.

Length distribution and sex ratio

In all three seasons, the trapped males were longer than the females. In 2002, males migrating to the spawning ground were 322.5 ± 29.4 mm long Sl ($t = 4.54$; $n = 15$; $P < 0.0001$), 275.5 ± 17.2 mm ($t = 3.24$; $n = 45$; $P < 0.0001$), while the lengths were 321.7 ± 19.3 mm ($t = 3.31$; $n = 36$; $P < 0.001$) in 2003 and 2004 respectively. In contrast, the standard length of a female was 244.0 ± 2.9 mm ($n = 84$) in 2002, 239.2 ± 3.2 mm ($n = 71$) in 2003 and 268.9 ± 3.2 mm ($n = 70$) in the season of 2004. The sex ratio between males and females was not significant

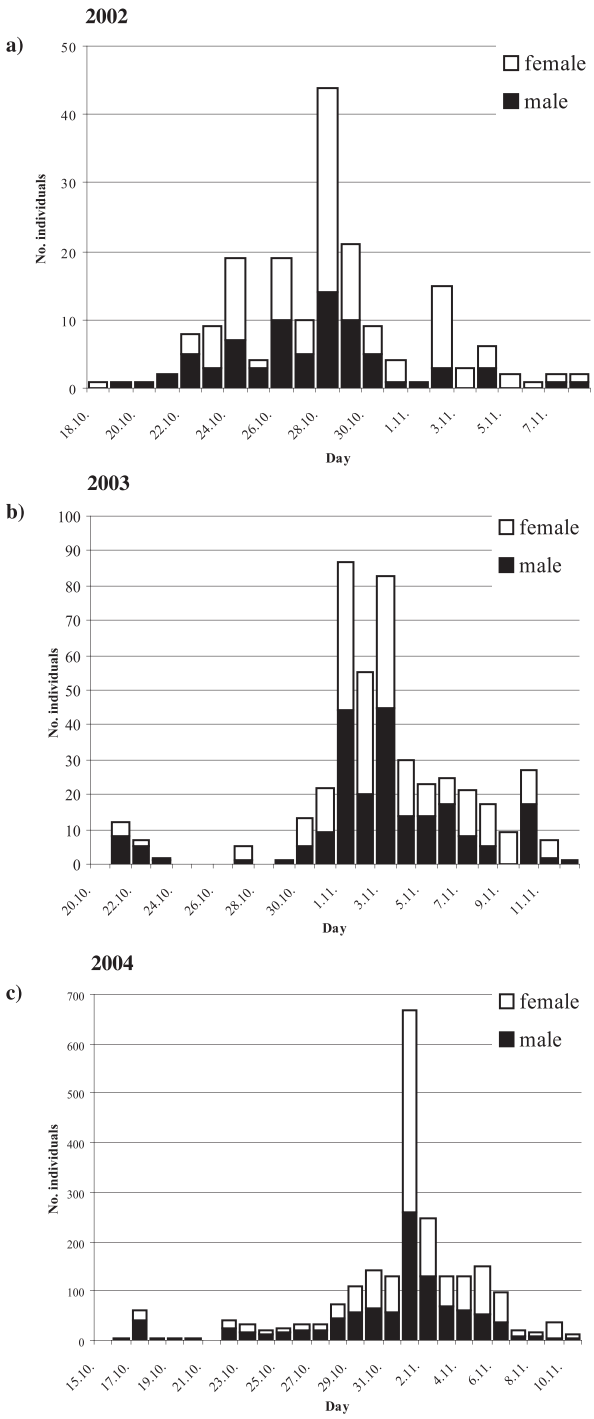

Fig. 3. Number of female and male brown trout on single days in the Morávka reservoir in the mentioned seasons. (White bars – females, Black bars – males).

only in 2003 ($P > 0.05$). In the seasons of 2002, the spawning migration involved more females than males (Table 2). Generally, there were more females than males migrating in the three seasons ($\chi^2 = 20.11$; $P < 0.00001$).

Table 2. Sex ratio of brown trout in the individual seasons in the Morávka reservoir (* - P < 0.05; ** - P < 0.01; *** - P <0.001; ns - not significant).

Year	Males	Females	Total	% Males	χ^2 - Value	Prob. Level
2002	79	108	187	42.2	4.49	0.0339 *
2003	217	230	447	48.5	0.39	0.5386 n.s.
2004	1016	1214	2230	45.6	17.58	<0.00001 ****

Diel activity pattern of the migration

The difference between the night and day spawning migrations was significant only in 2002. In this season, brown trout migrated more during the day (Wilcoxon, z = 3.21; P<0.01). There were 130 brown trout individuals in total (69.6%) migrating during the day (8:00 a.m. – 6:00 p.m.). The diel activity, in this season, showed a multimodal distribution. Most brown trout were caught between 6:00 a.m. and 8:00 a.m. (13.9 %) and between 2:00 p.m. and 4:00 p.m. (15%), (Fig. 4a). The diurnal analysis of the later season was not significant. In 2003: (Wilcoxon, z = 1.55; P = 0.1213) and in 2004 (Wilcoxon, z = 1.12; P = 0.3605) respectively, the diel activity of spawners showed the single mode distribution (Fig. 4b, 4c). In 2003, most movements of brown trout took place between 12:00 a.m. and 4:00 p.m. (29.5 %), (Fig. 4b). Similarly in 2004 most activity of spawners took place from 4:00 p.m. to 6:00 p.m. (20.1%), (Fig. 4c). The difference in diurnal activities of males and females during the three years was not significant (Wilcoxon, P>0.05).

Impact of environmental variables on spawning migration

The impact of environmental variables on the duration of trout migration was tested by multiple regression analyses. The values of partial regression coefficients b_i (T-value) were tested for individual abiotic factors. The trout migration out of the reservoir to the main tributary started, in all monitored years, when the water temperature in the reservoir decreased below 8°C and the water temperature in the tributary varied between 5 and 7°C, though the consequent variation in water temperature in the reservoir (increases or decreases), did not have a significant influence on the migration (P >0.05), (Table 3).

In contrast, changes in the water temperature in the tributary proved to be an important factor influencing the migration duration. However, there were significant differences in between the individual years even there. When the migration peaked in 2002, the water temperature varied between 6.0 and 6.2°C, while, in 2003, the water temperature varied between 7.0 and 7.4°C, when the fish activities peaked. In 2004, this temperature was 8.2°C (Fig. 5). The relation between the water temperature and the number of migrating trout was significant in 2003 (T-Value = 4.1608; P<0.001) and 2004 (T-Value = 5.4887; P<0.0001) (Table 3). The impact of the temperature was not significant in the season of 2002 (P>0.05).

The flow rate had a fundamental impact on the migration activity of spawners. In 2004 especially there was a strong correlation between flow rate and the increasing number of spawners. The main reason was a low flow rate in the period from 15 October to 31 October. Its average value was 0.29 $m^3.s^{-1}$. The sudden increase in the flow rate on 1 November,

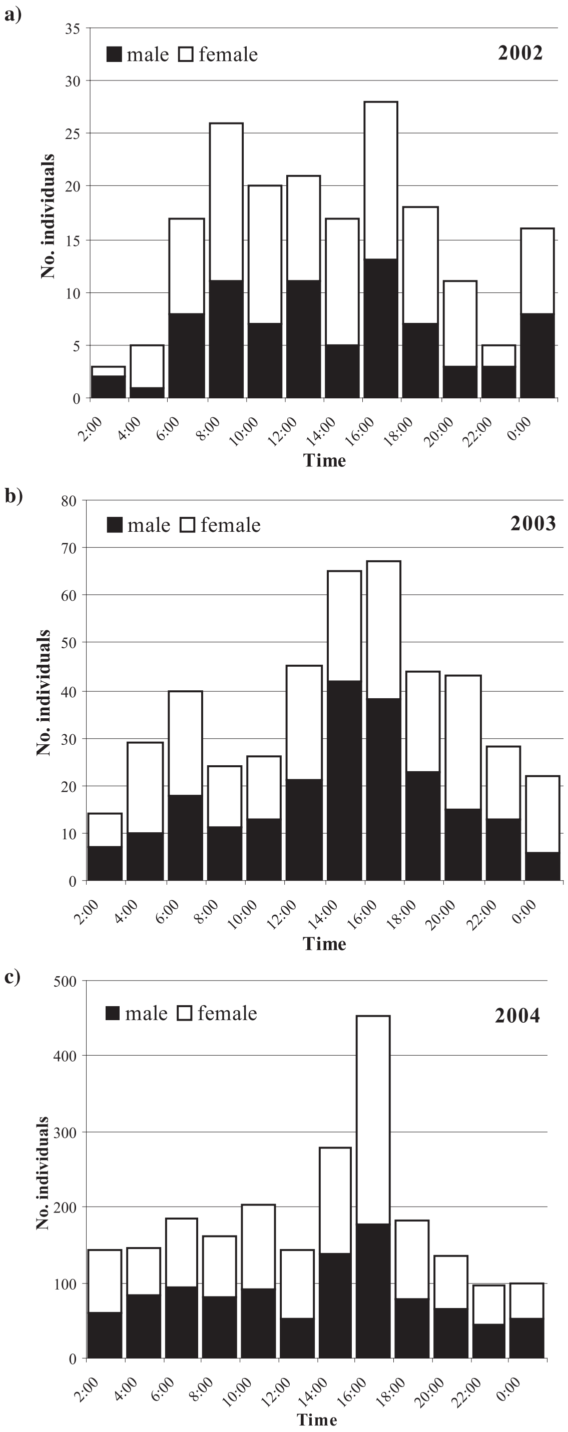

Fig. 4. The day activity pattern of the spawning migration. Total number of brown trout in two hour periods in this single year in the Morávka reservoir. (White bars – females, black bars – males).

Table 3. The relationship between the number of individuals (dependent) and environmental factors (independent) in the individual seasons in the Morávka reservoir (MULTIPLE REGRESSION, T-Value – the value test of the single partial regression coefficient b_i), Prm – water flow, Sr – precipitation, Tvn – water temperature in the reservoir, Ttrib – water temperature in the tributary, (* - P < 0.05; ** - P < 0.01; *** - P <0.001; ns - not significant).

2002

Independent Variable	Regression Coefficient	Standard Error	T-Value	Prob. Level	
Prm	-11.53646	4.479513	-2.5754	0.019655	*
Sr	-0.20519	0.457284	-0.4487	0.659301	n.s.
Tvn	10.81532	6.998096	1.5455	0.140645	n.s.
Ttrib	-1.21210	3.755878	-0.3227	0.750842	n.s.

For all variables:
R-Squared = 0.3809
ANOVA F-Ratio = 2.61 P = 0.07196 n.s.

2003

Independent Variable	Regression Coefficient	Standard Error	T-Value	Prob. Level	
Prm	-6.96309	21.59988	-0.3224	0.751105	n.s.
Sr	2.93843	1.26401	2.3247	0.032731	*
Tvn	-12.58963	3.34378	-3.7651	0.001544	**
Ttrib	11.10580	2.66917	4.1608	0.000655	***

For all variables:
R-Squared = 0.7175
ANOVA F-Ratio = 10.79 P = 0.00015

2004

Independent Variable	Regression Coefficient	Standard Error	T-Value	Prob. Level	
Prm	248.71470	48.85434	5.0909	0.000042	****
Sr	11.20995	1.51936	7.3780	0.000001	*****
Tvn	-1.23227	16.92849	-0.0728	0.942629	n.s.
Ttrib	32.77	5.97043	5.4887	0.000016	****

For all variables:
R-Squared = 0.9014
ANOVA F-Ratio = 50.3 P<0.00001

up to 1.1 $m^3.s^{-1}$, proved to be a strong stimulus, which caused the increase in the number of migrating individuals (T-Value = 5.0909; P<0.00001), (Table 3). In the seasons 2002 and 2003, the flow rates were relatively high and varied within the range of 0.66 $m^3.s^{-1}$ and 1.9 $m^3.s^{-1}$ during the entire monitoring periods. The increase or decrease in the flow rate thus did not have a fundamental impact on the migration duration in 2002 (T-Value = -2.5757; P = 0.0195) and in 2003 (T-Value = - 0.3224; P<0.05).

Discussion

We monitored spawning brown trout migrations every year from its beginning to the end. The migrations lasted for relatively short periods of 22 days in 2002, 24 days in 2003, and 27 days

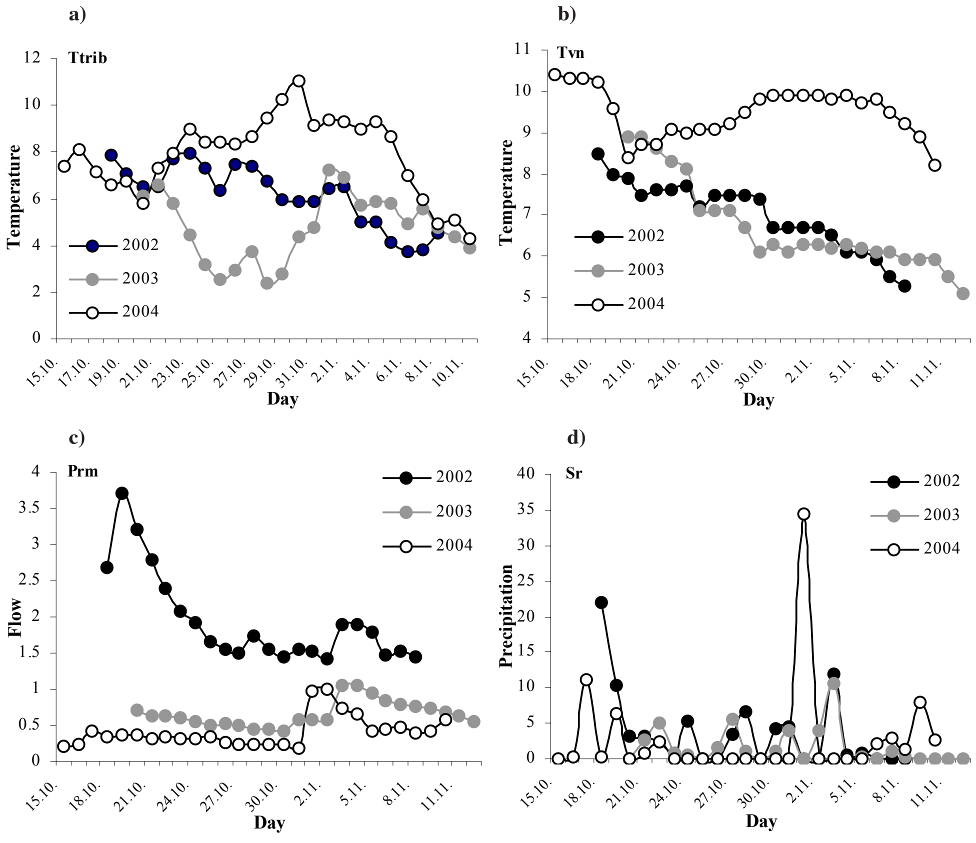

Fig. 5. The course of environmental variables during the three years (2002–2004) in Morávka reservoir: a) Trib – water temperature (°C) in the tributary, b) Tvn – water temperature (°C) in the reservoir, c) Prm – water flow ($m^3.s^{-1}$), d) Sr – precipitation ($mm.m^{-2}$).

in 2004. Libosvárský (1967, 1974) followed the duration of trout spawning from the end of September to the mid December, i.e. 80 ± 5 days on average. During the three years of his spawning migration monitoring, the first and, at the same time, the main migration peak took place always between 20 October and 10 November. This corresponds with our results. Also Sakowicz & Szczerbowski (1965) found that the peak of the trout spawning migration from the Wdzydze Lake (in Poland) took place between 5 and 10 November. We believe that the different number of migrating brown trout in the individual years of monitoring related to the existing successive stages of ichtyocenosis in the newly filled up reservoir. We assume that the number of migrating brown trout is the result of the intensive releases of pre adult individuals (Table 1). The number might be also influenced, in a negative way, by predators - herons (*Ardea cinerea*) and otters (*Lutra lutra*), are regularly active in the reservoir area. Also Jonsson & Jonsson in 2002 mentioned the predation by mink (*Mustela vison*) in relation to migrating brown trout. The use of a trap for the monitoring of brown trout spawning migrations proved to be a very efficient method. A similar mechanism was also used by Carlsson et al. in 2004 and Rubin et al. in 2005.

The sex ratio differed a lot from 1:1 in the first year of our monitoring. However, the ratio was balanced in the following seasons (2003 and 2004). Libosvárský (1967,

1974) found similar results in the Hadůvka brook. He described a balanced sex ratio in the spawning shoal in years 1965 and 1966, but he found an important difference in favour of males in 1967. A higher number of females in the spawning shoal during five years of monitoring (1957–1961) were reported also by S a k o w i c z & S z c z e r b o w s k i (1965). In contrast, R u b i n et al. (2005) reported a higher percentage of males at the beginning and at the end of migration activities.

In contrast, we did not find conclusive differences in the number of fish migrating during days and nights in 2003 and 2004. Telemetrically monitored trout in Belgian rivers migrated more at night than during day hours (O v i d i o et al. 1998). R u s t a d b a k k e n et al. (2004) studied the reproductive trout migrations in the river Brumunda (a small Norwegian river) and they reported a connection between the water flow rate and the day migration activities. Trout moved more at night only at low water flows and there were no differences found between the day and night hours when the river water levels were higher. Charr monitored in the St. Michel Lake (Canada) undertook spawning migrations at night (B a r i l & M a n g a n 2002), but in a different lake, Scott Lake (in Canada), the most intensive spawning and migration to red sites took place between 12:00 a.m. and 2:00 p.m. (B l a n c h f i e l d & R i d g w a y 1997). This comparison of results of our research shows that there are some conclusive differences between spawning migrations of populations of fish within the salmon family, that live in natural river systems, and populations, that live permanently in reservoirs or lakes. The timing and duration of spawning migrations of salmon fishes are influenced and managed by environmental factors (J o n s s o n 1991, O v i d i o et al. 1998, R u s t a d b a k k e n et al. 2004). Impacts of abiotic factors on the trout migration within conditions existing in the Morávka reservoir differed between individual years. The inconsistent correlation in 2002 might be probably explained by the fact that no significant changes in the environmental factors took place in the short period of our monitoring (22 days). Salmon fishes (brown trout and brook charr) react strongly to sudden changes in the water temperature. When the temperature suddenly decreases, the number of migrating fish usually reduces, while they start migrating again after a fast increase in the water temperature (L i b o s v á r s k ý 1967, 1976, B a r i l & M a n g a n 2002). Similarly, B l a n c h f i e l d & R i d g w a y (1997) reported that the peak in the migration activities of charr was preceded by a sudden decrease and subsequent increase in the water temperature. The decrease in migration activities of trout, when the water temperature is below 3°C, relates to the decrease in enzyme activities in blood plasma (L u s k o v á & L u s k 1995). The relation of individual environmental factors and their interaction, in the correlation with the lower or higher speeds in the migration of tagged trout, were studied by O v i d i o et al. (1998). O v i d i o & P h i l i p p a r t (2002) found that an important factor that influences the spawning is water flow although its effect on the migration was important, only in 2004 in our study. The migration behaviour of the telemetrically monitored trout in the Mjøsa Lake (Norway) and the effect of the water flow in a tributary were studied by A r n e k l e i v & K r a a b ø l (1996). Their results show that trout react to higher water flows with significantly increased intensity of their migration. The increased migration activities at higher flows were reported also by R u b i n et al. (2005). The relation between the river water flow and the number of migrating individuals was followed also by L i b o s v á r s k ý (1976). The effect of the water temperature and the water flow on the spawning migration of trout females was also monitored by S v e n d s e n et al. (2004). J o n s s o n (1991) also described abiotic factors (the water temperature and the water flow rate) as important factors, which stimulate the upstream and downstream migrations during a year. Results of our field research and their comparison with the results by other authors clearly show that they are not the only individual environmental variables, which without doubt significantly influence the duration of reproduction movements. The interactions between these abiotic factors are also important.

It seems that the three year study of brown trout migration from the newly filled (2000) Morávka reservoir achieved statistically assessable data. The results of this study suggest that the timing, intensity abd duration of brown trout migration in an artificial water environment do not differ from natural water systems (lakes and flowing waters). As in other kinds of the environment, the most important factor, which positively affects the intensity of the spawning migration, is the sudden increase in the water flow rate.

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