Growth analysis of chub, *Leuciscus cephalus* (L.), and dace, *Leuciscus leuciscus* (L.), in the Úpoř stream using growth data of recaptured marked fish

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ABSTRACT: The length growth of chub and dace was observed. The scale method was used as well as data gained from recaptured individuals which were marked with visible elastomer tags and platinum wire tags with a coloured code placed under the first bony ray of the dorsal fin. The length-weight relationship for chub could be explained by the equation $w = 0.00001.l^{3.067}$ ($r^2 = 0.96$). The average condition coefficient reached 1.49. The growth was balanced, gradually slowing down. Von Bertallanffy growth equation had the form $L_t = 245.47(1 - e^{-0.206(t + 0.0333)})$. The average value of instantaneous monthly growth rate (G_m) ranged between 0.4 and 4.3 (in %). Mean G_m of particular age groups gradually decreased. G_m varied seasonally, annually and in different parts of the stream. The length-weight relationship for dace was $w = 0.000009.l^{3.0948}$ ($r^2 = 0.97$). The mean condition coefficient reached the value of 1.11. The length growth was balanced, gradually decreasing. Von Bertallanffy equation had the form $L_t = 216.28(1 - e^{-0.2536(t + 0.26094)})$. The instantaneous monthly growth rate ranged between –1.57 and 10.38 (in percentage). This indicator fluctuated according to the age, season and year.

Keywords: chub; dace; growth; instantaneous growth rate

Chub is usually considered as an unpretentious fish species which occurs commonly in localities with different conditions, both natural and artificial ones (Arlinghaus and Wolter, 2003). Many authors often observed the growth of this fish species in connection with its usual occurrence. Although the majority of contributions about the growth of chub describes its biology or growth in rivers (Hanel, 1982; Švátora and Pivnička, 1986, 1989; Türkmen et al., 1999) and reservoirs (Leontovyč, 1974; Hanel, 1982; Švátora and Pivnička, 1986; Ünver, 1998), the growth of chub was also studied in rivulets, brooks or small streams (Hanel, 1984; Vlach and Švátora, 2000). The growth of dace was investigated in bigger streams and reservoirs (Vostradovský, 1961; Leontovyč, 1980; Švátora and Pivnička, 1986, 1989), as well as in small streams (Hanel, 1984; Vlach and Švátora, 2000).

All the contributions mentioned above used the scale method. Hartvich and Kubečka (1989) pointed out the inappropriateness of this method for evaluation of seasonal growth changes.

Besides such data this contribution contains a comprehensive set of growth data acquired by the method of recapturing marked specimens of both fish species. This data enabled us to evaluate relative growth and growth dynamics.

The study area

The Úpoř brook is a right tributary to the Berounka River near the village of Týřov. The drainage area of this stream is 39.5 km^2, the length of the stream is 11.2 km and the average flow rate in the estuary is 0.08 m^3/s. This stream is typically fragmented into pools and riffle and rapids areas. It belongs to the Landscape Protected Area Křivoklátsko and it is not managed by fishermen (Figure 1). The length of the study area was 4 km and the study area was de-

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Figure 1. Map of the locality

fined as a part between a small pond in the Broumy village and the estuary. This area was divided into three parts of approximately equal lengths but with differences in the habitat structure.

The fish assemblage of this stream is typical of this type of lowland small stream: apart from chub and dace it is also inhabited by brown trout (*Salmo trutta*), bullhead (*Cottus gobio*), stone loach (*Barbatula barbatula*) and occasionally by barbel (*Barbus barbus*), grayling (*Thymallus thymallus*) and other fish species, mainly escaped from the Broumy pond. The index of biotic integrity reached 44 points here (Pivnička et al., 1996).

MATERIAL AND METHODS

All growth data were collected between 2000 and 2003. In this period 27 catches were made. Individual pools or randomly chosen whole sections of the stream were fished using the method of electrofishing (devices TRA 2 – pulsed 450V; MK-1 pulsed 225/300V; LENA pulsed 225/300V). The captured fish were measured (standard length – *longitudo corporis*), weighed, and scales were removed from the end of their pectoral fin, and some were individually marked with tags made from platinum wire with coloured plasting tubing under the first bony ray of the dorsal fin. The visible implant elastomer tags were used in the last year of the experiment. The used method was described by Dušek et al. (2003).

The growth of chub was calculated from length and age data of 93 recaptured marked specimens and 142 unmarked specimens. The average recapture rate was 25.9%. The growth of dace was similarly calculated using 67 growth data from 27 recaptured marked fishes and 72 unmarked fishes. The recapture rate was 16%. The age structure of these samples is presented in Figure 2.

The length growth was calculated using both length data of recaptured fish and the scale method. A length-weight relationship was estimated from the lengths and weights of all the fish using the equation:

$$w = a \times l^b$$

The condition coefficient according to Fulton's equation was calculated as follows:

$$k = \frac{w_t}{l_t^b}$$

where: w_t = the weight at the time of capture
l_t = the standard length at this time
b = the exponent which is identical to that in the length-weight relationship

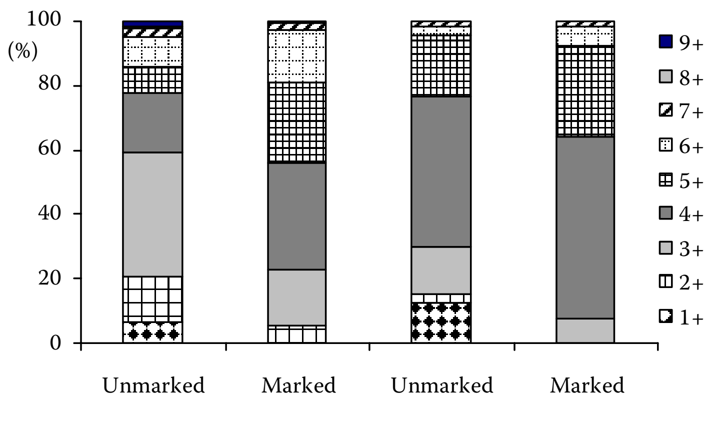

Figure 2. Age structure of marked and unmarked fish (*L. cephalus* and *L. leuciscus*)

Relative growth was evaluated using Brody's instantaneous monthly growth rate G_m as a good indicator according to the equation:

$$G_m = \frac{\ln(l_t) - \ln(l_{t-1})}{t}$$

where: l_t = the standard length at the time t
l_{t-1} = the standard length at the time t–1
t = the time period (number of months)

The large amount of growth data enabled us to evaluate the average growth in particular years, seasonal growth, growth of different age groups and growth in different parts of the stream.

Von Bertallanffy's growth equation was estimated according to the equation:

$$L_t = L_\infty (1 - e^{-K(t - t_0)})$$

where: L_t = the standard length at the age t
L_∞ = the asymptotic body length
t = the age of fish
t_0 = the hypothetical time at which the fish reaches zero length

All the statistical estimations were calculated by means of Open Office.

RESULTS

Chub (*Leuciscus cephalus*)

The length-weight relationship was estimated using data on the length and weight of all captured fish. This relationship was expressed by $w = 0.00001\, l^{3.0667}$ (r^2 = 0.96). The average condition coefficient reached the value 1.49.

The total annual growth was evaluated on the basis of comparisons of average instantaneous monthly growth rates (G_m). In 2000 G_m reached the value 1.88 while it was 1.46 in 2001, 1.71 in 2002 and 1.89 in 2003 (in %). The observed differences are significant (ANOVA, F = 2.966; P = 0.032). The growth in 2001 was the slowest (Table 1). The average G_m of particular age groups gradually decreased according to the relationship $y = -0.0144 \times \ln(x) + 0.0325$ (r^2 = 0.97) (Figure 3). The seasonal growth of particular age groups was evaluated only in 2001 and 2003 because a sufficient amount of length data was available in these years (all values of G_m in %).

2001

The relative growth of the 2nd age group intensively increased in July (from 0.7 to 2.2) and then gradually decreased (0.7 in November). The 3rd age group presented fast growth in July (increase of G from 1.14 to 4.51) and then it slowly decreased (1.15 in November) as well as the 4th age group (from 1.8 in May gradually to 2.11 in July). The growth of this age group showed a second peak in October (1.98). The slowest growth of the 4th age group was observed in November (0.7).

2003

The instantaneous growth rate of the 1st age group increased gradually from the zero level in May to the value 5.9 in September. This level remained to October and rapidly decreased in November (1.8). The 2nd age group presented gradually increasing growth (from 1.41 in May to 4.05 in October). A similar level of growth (3.4) continued to the first part of November. The growth of the 3rd age group was high (2.21) already in May but culminated in September when it reached the value 2.6. It rapidly fell in November (0.5). The 4th age group had a relatively balanced growth about the value 2.5. The growth in May was the fastest (3.4), the slowest in November (0.1). The other observed differences in the growth of this age group are not statistically significant. The growth of the 5th age group was

Table 1. Instantaneous growth rate of *L. cephalus* according to years

	2000	2001	2002	2003
n	106	183	61	129
Mean	0.019	0.015	0.017	0.019
SD	0.012	0.013	0.010	0.020
Min	–0.008	–0.033	0.005	–0.027
Max	0.069	0.065	0.041	0.080

Table 2. Seasonal variations of instantaneous monthly growth rate (G_m) (*L. cephalus*)

	May	June	July	August	September	October	November
n	39	21	26	24	19	37	40
Mean	0.013	0.017	0.029	0.013	0.026	0.026	0.010
SD	0.021	0.012	0.020	0.012	0.021	0.018	0.012
Min	–0.027	–0.007	0.005	–0.003	0.006	0.000	–0.007
Max	0.055	0.045	0.083	0.057	0.070	0.078	0.044

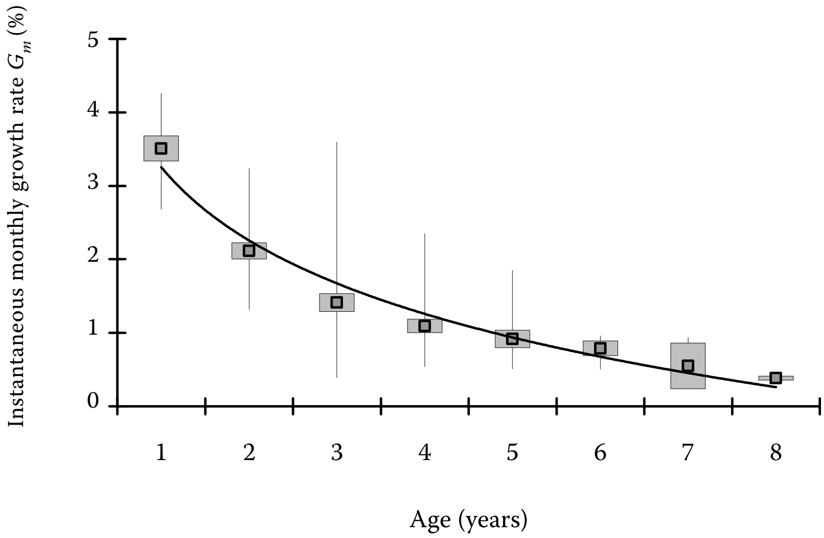

Figure 3. Instantaneous monthly growth rate according to age (*L. cephalus*)

slow (below 1.0) and had two peaks: in July (2.14) and in November (3.55). It is possible to claim three significant peaks in the growth of all fish in the whole period: in July, September and October. The slowest growth of chub in the whole period was in November (Table 2).

Growth in different parts of the stream was evaluated as well. The instantaneous monthly growth rates of all fish captured in particular sections were compared using the analysis of variance, and significant differences ($P > 0.05$) in relative growth in these sections were found (Table 3).

Table 3. Instantaneous growth rates of *L. cephalus* in different parts of the stream

	Part of the stream		
	1	2	3
n	27	54	26
Mean	0.017	0.014	0.011
SD	0.012	0.006	0.005
Min	0.000	0.002	0.002
Max	0.051	0.030	0.027

The total length growth was balanced and gradually slowing down. The shape of the curve changed from the 7th age group, which could be caused by lower numbers of fish in the older age groups. Von Bertallanffy's growth curve was established from 255 specimens (using both marked and unmarked fish) and had the shape $L_t = 245.47\ (1 - e^{-0.206(t + 0.03337})$ (Table 4 and Figure 4).

The length growth of particular age groups (only marked fish) is obvious from Figure 5. The growth of the age groups in the observed period could be approximated by these linear or polynomial models:

$y = -4E\text{-}06x^2 + 0.3507x - 7739.6$ ($r^2 = 0.93$) for the 1st age group,
$y = 4E\text{-}08x^3 - 0.0044x^2 + 165.73x - 2E{+}06$ ($r^2 = 0.87$) for the 2nd age group,
$y = 4E\text{-}11x^4 - 6E\text{-}06x^3 + 0.318x^2 - 7862.4x + 7E{+}07$ ($r^2 = 0.79$) for the 3rd age group,
$y = 2E\text{-}08x^3 - 0.002x^2 + 73.046x - 912214$ ($r^2 = 0.78$) for the 4th age group,
$y = 0.0244x - 701.88$ ($r^2 = 0.91$) for the 5th age group,
$y = 0.024x - 701.88$ ($r^2 = 0.91$) for the 7th age group,

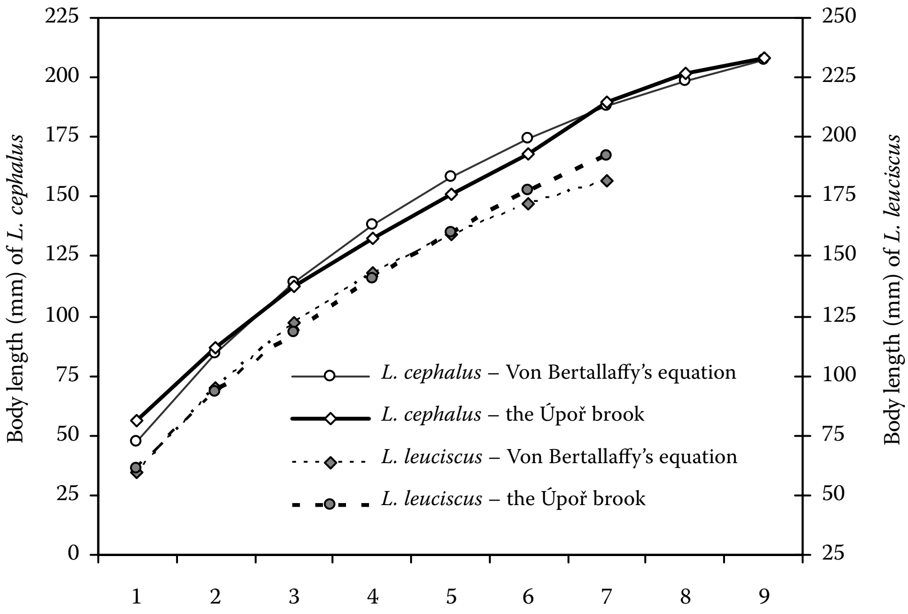

Figure 4. Length growth of *L. cephalus* and *L. leuciscus* in the Úpoř brook

$y = 2E\text{-}07x^3 - 0.0171x_2 + 639.93x - 8E + 06$ ($r^2 = 0.92$) for the 1st age group in 2001,
$y = 0.0927x - 3409.7$ ($r^2 = 0.85$) for the 1st age group in 2002.

Polynomial models show two increases in growth in July and in August 2001 (differences are more obvious when models are created only for this year) as well as in 2003 and slower growth in autumn 2001. Data for 2002 is not sufficient for such evaluation (Figure 6).

Dace (*Leuciscus leuciscus*)

The length-weight relationship was estimated from 142 values of the length and weight of fish and had the form $w = 0.000009.l^{3.0948}$ ($r^2 = 0.97$). The average condition coefficient reached the value 1.11. Gradual decrease in the condition coefficient in older age groups can be characterized by the relationship $y = -0.000033x^3 + 0.0004x^2 - 0.0019x + 0.0138$ ($r^2 = 0.79$). The instantaneous monthly

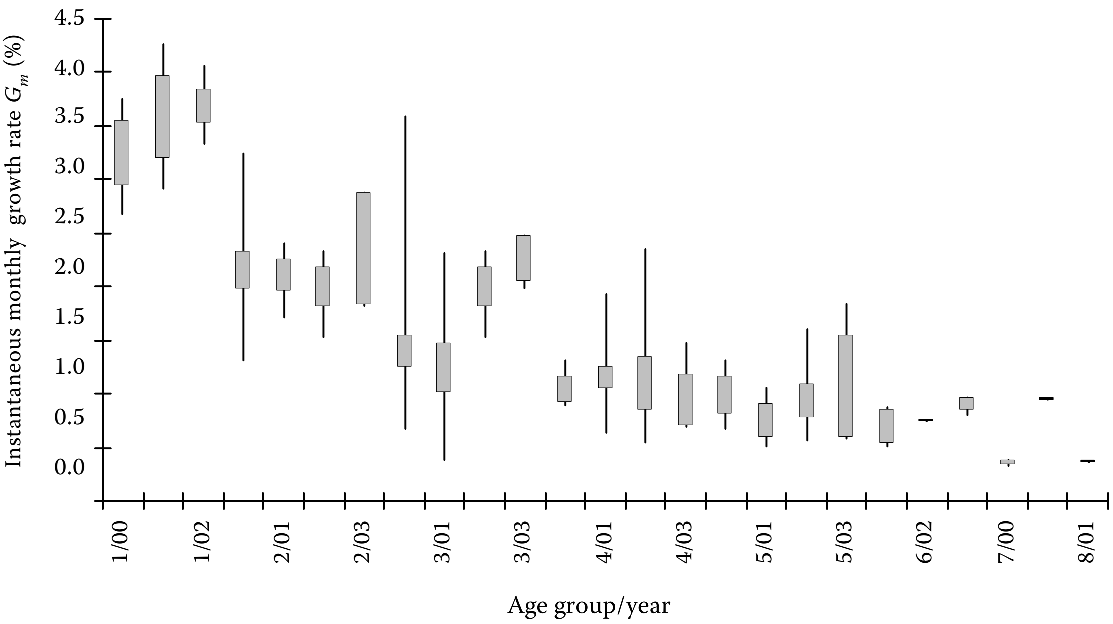

Figure 5. Instantaneous monthly growth rate according to age groups and years (*L. cephalus*)

Table 4. Length growth (in mm) of *L. cephalus* in the Úpoř brook in 2000–2003

Age group	*n*	L1	L2	L3	L4	L5	L6	L7	L8	L9
I	10	60.3 (55–66)								
II	27	56.2 (49–64)	85.6 (73–100)							
III	66	59.2 (47–69)	89.9 (67–109)	113.9 (98–132)						
IV	55	56.5 (48–69)	87.6 (70–110)	113.9 (96–135)	134.3 (115–156)					
V	33	56.9 (46–64)	85.8 (70–108)	112.4 (94–132)	134.2 (113–155)	151.7 (136–173)				
VI	30	55.6 (45–69)	84.0 (71–105)	108.8 (94–126)	130.5 (114–146)	150.8 (128–164)	167.7 (152–178)			
VII	6	58.3 (50–64)	84.7 (73–96)	110.3 (101–118)	137.9 (123–147)	164.7 (144–181)	181.8 (161–193)	197.8 (175–208)		
VIII	3	60.5 (51–66)	88.9 (74–101)	120.0 (115–135)	143.9 (137–151)	166.8 (166–167)	180.2 (179–182)	198.1 (194–200)	204.8 (202–210)	
IX	2	56.8 (51–63)	85.4 (71–100)	106.8 (98–126)	125.2 (106–144)	145.0 (124–166)	166.8 (147–187)	183.2 (161–205)	198.0 (178–218)	208.3 (188–229)
Total	232	57.8	86.5	112.3	134.3	155.8	174.1	193.0	201.4	208.3
w (g)		2.53	8.71	19.40	33.61	52.97	74.46	102.17	116.33	129.12

growth rate was used as a good indicator of the relative growth of dace. However, the insufficient amount of growth data did not enable us to evaluate the relative growth in detail. Average G_m in the period 2000–2002 is presented in Table 5. No significance was found in the differences between particular years (ANOVA, $F = 0.645$, $P = 0.52$). Seasonal growth was evaluated for the whole population only in 2001. The maximum value of instantaneous growth rate was observed in June (2.8), the

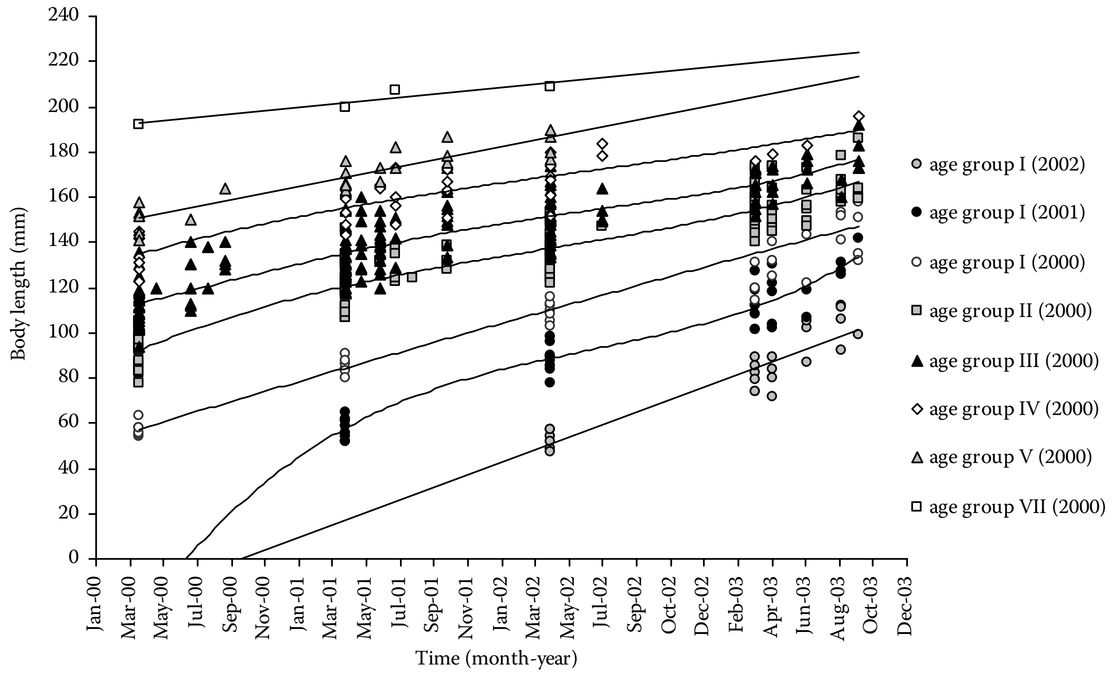

Figure 6. Length growth of different age groups of *Leuciscus cephalus* in 2000–2003

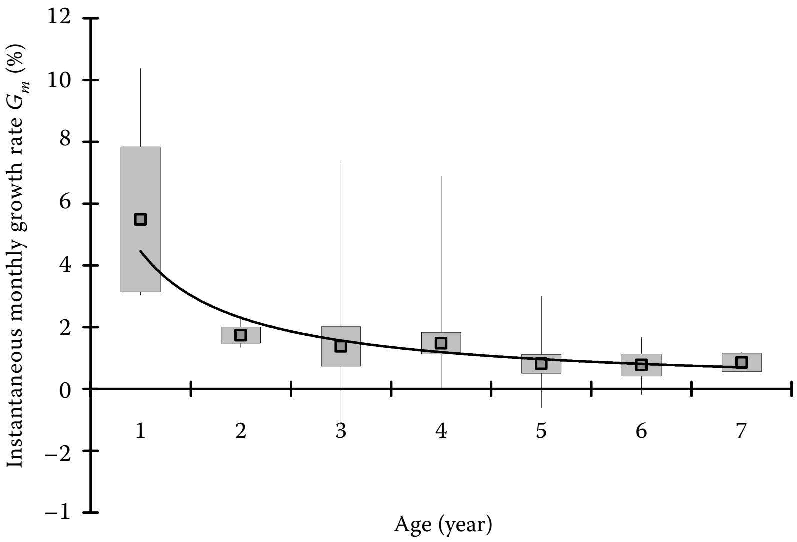

Figure 7. Instantaneous monthly growth rate according to age (*L. leuciscus*)

Table 5. Instantaneous monthly growth rates (G_m) of *L. leuciscus* ac-cording to years

	2000	2001	2002
n	41	77	9
Mean	0.016	0.014	0.009
SD	0.014	0.017	0.003
Min	–0.002	–0.016	0.004
Max	0.072	0.104	0.015

minimum in September (0.5). Average G_m gradually slowed down in age groups in accordance with the trend $y = 0.00446x - 0.952$ ($r^2 = 0.91$) (Figure 7).

The length growth of all (marked and unmarked) fish is presented in Table 6 and Figure 5 as well as von Bertallanffy's equation estimated from 255 specimens of dace. This equation had the form $L_t = 216.28\ (1 - e^{-0.2536(t + 0.26094)})$.

Figure 8 shows the average length growth of particular age groups and the models characterising the growth of these age groups. These linear and

Table 6. Length growth (in mm) of the *L. leuciscus* in the Úpoř brook in 2000–2003

Age group	*n*	L1	L2	L3	L4	L5	L6	L7
I.	4	58.8 (52–68)						
II.	3	61.5 (59–64)	91.0 (83–98)					
III.	14	65.4 (58–70)	97.8 (85–108)	122.0 (106–136)				
IV.	47	64.5 (54–71)	95.8 (81–117)	121.9 (103–136)	139.2 (122–150)			
V.	22	61.9 (52–68)	91.6 (77–104)	117.8 (103–135)	138.6 (126–156)	155.0 (141–168)		
VI.	4	59.9 (57–62)	92.4 (87–99)	119.6 (113–124)	150.5 (144–161)	166.8 (155–186)	177.5 (169–197)	
VII.	2	56.0 (53–59)	95.3 (91–100)	118.1 (115–122)	141.7 (135–148)	163.3 (155–172)	181.4 (172–191)	192.3 (179–206)
Total	96	61.1	94.0	119.9	142.5	161.7	179.5	192.3
w (g)		3.0	11.5	24.4	41.7	61.6	85.1	105.3

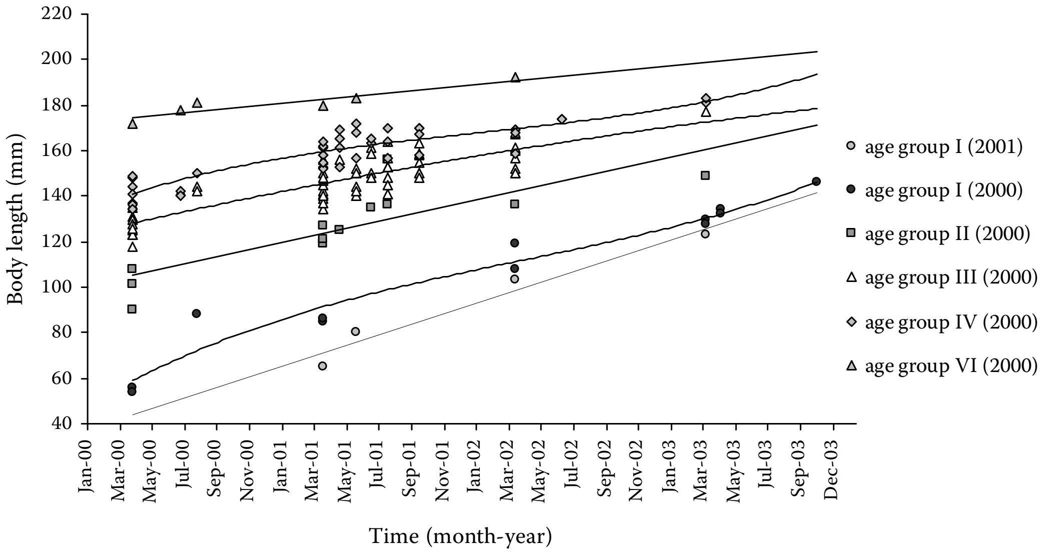

Figure 8. Length growth of different age groups of *Leuciscus leuciscus* in 2000–2003

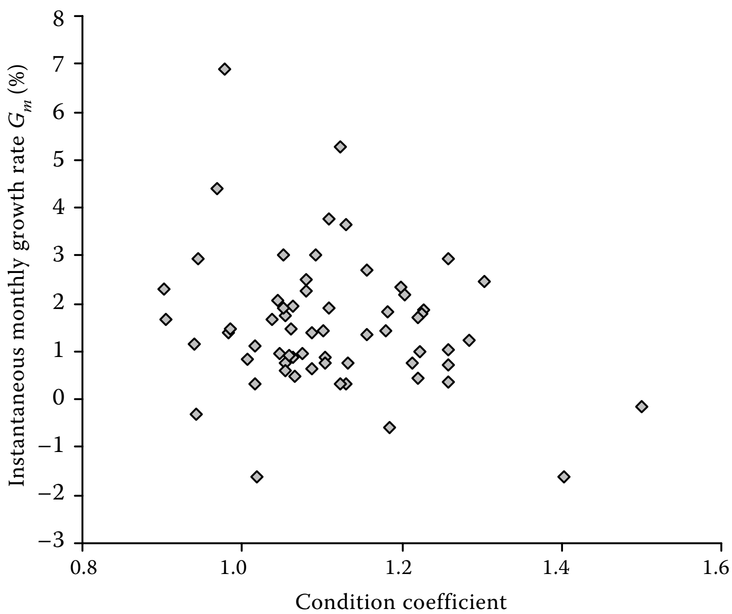

Figure 9. Relationship between condition coefficient and instantaneous growth monthly rate of *L. leuciscus*

polynomial models were described by these equations:

y = 4E-08x^3 – 0.0047x^2 + 176.06x – 2E+06 (r^2 = 0.96) for the 1st age group,

y = 0.0505x – 1743.5 (r^2 = 0.70) for the 2nd age group,

y = –1E-05x^2 + 0.7627x – 14771 (r^2 = 0.74) for the 3rd age group,

y = 4E-08x^3 – 0.004x^2 + 149.51x – 2E + 06 (r^2 = 0.82) for the 4th age group,

y = 0.0223x – 642.11 (r^2 = 0.85) for the 6th age group,

y = 0.0746x – 2687.5 (r^2 = 0.96) for the 1st age group in 2001.

Like in chub, polynomial models show accelerated growth in summer 2001 and slowing down in autumn 2001.

DISCUSSION

Repeatedly migrating fish between the main stream and a tributary have an influence on the

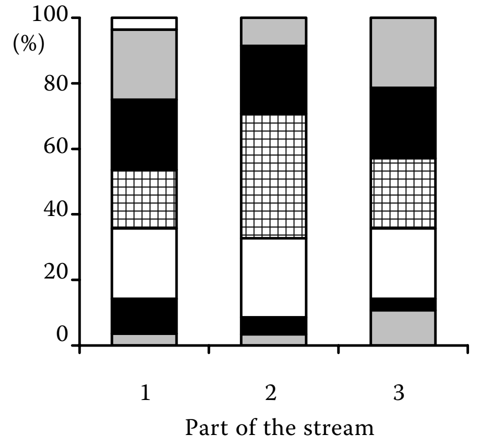

Figure 10. Age composition in three parts of the stream

structure of fish assemblage (Verbickas and Kesminas, 1999) and mortality (McGarvey and Feenstra, 2002) as well as on their growth as Vlach and Švátora (2000) reported.

These populations of chub and dace are allochthonous in the Úpoř brook, all the specimens of these fish species originated from the main watercourse, the Berounka River, and they migrated to the Úpoř brook. The migration of both species was repeatedly proved even in this stream. It was discovered that migrating individuals made up 40.3% of the chub population and 32.5% of the dace population (our own observed data). But both the growth evaluation using growth tag-recaptured data and the evaluation of relative growth enable us to distinguish fish migrating between the main watercourse and the tributary, and to evaluate their influence on the average population growth. Vlach et al. (in prep.) found out that a portion of fish behaving in this way was small and did not influence the total growth.

It is not possible to easily interpret the observed differences in seasonal instantaneous growth rates without global knowledge of all factors that can influence the length growth such as water conditions, temperature, movements and so on. The quantity and quality of food belong among these factors. The attempt to find a relationship between the instantaneous growth rate and the condition coefficient could not bring success (Figure 9) because this indicator is influenced by many factors (sexual differences, maturity or day-lasting quality grazing). That is why the condition coefficient cannot explain an instantaneous trend of length growth. But the food condition plays a dominant role in seasonal changes in growth (Frank, 1959; L'abée et al., 2002). High rates of growth in summer can be explained by an increase in food supply consisting above all of terrestrial insects mainly ingested at this time (Vlach et al., in prep.). Other changes (e.g. in early autumn in 2003) in growth are connected with changes on water conditions. Disturbances resulting from the rising of water levels could increase the amount of drift (Death, 2003) and food conditions could get better at that time.

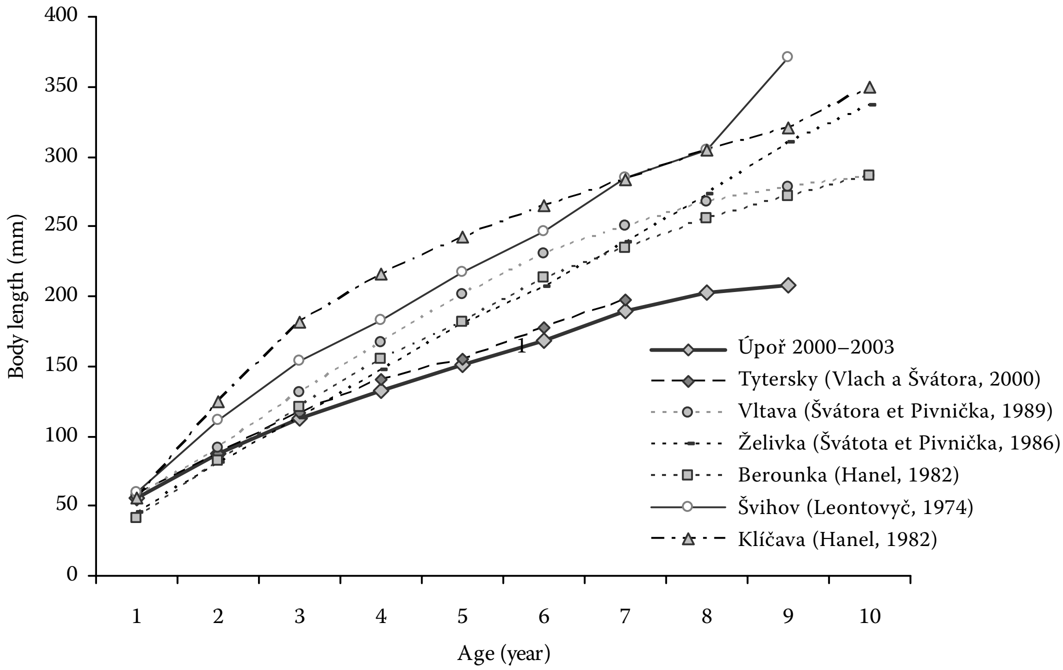

Figure 11. Length growth of *L. cephalus* in different localities

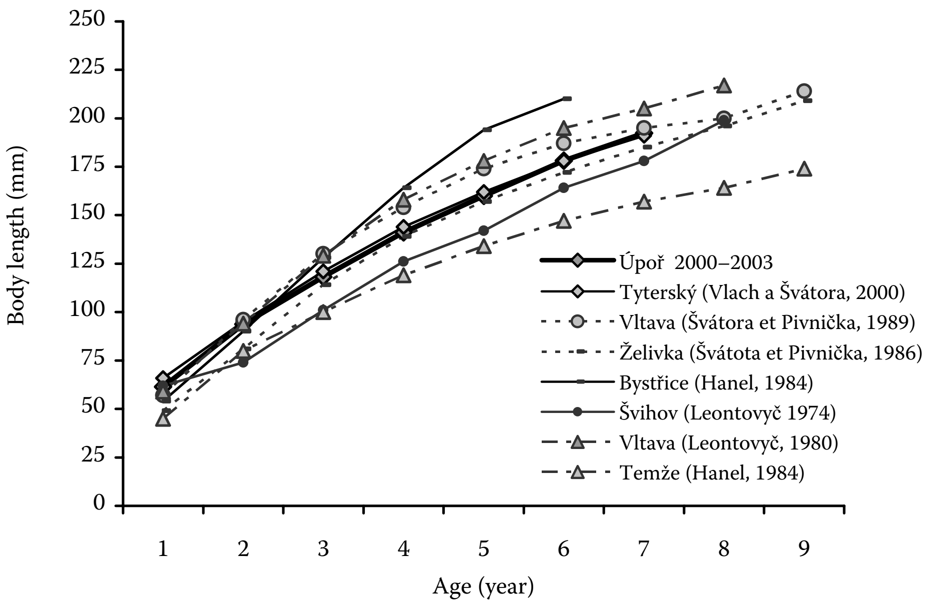

Figure 12. Length growth of *L. leuciscus* in different localities

The observed differences in the growth of chub in different sections of the stream can be explained by the presence of large pools in the upper and the middle part. Smaller pools connected with relatively deeper rapids and riffle areas in the lower part of the stream made good conditions for migration (Lonzarich et al., 2000; Peňáz et al., 2002); such longitudinal movements consumed energy usable for the length growth. The differences in growth could be explained by the divergence of age structure in particular sections of the stream, but these divergences were not high as shown in Figure 10. Moreover, younger, fast-growing fish were more highly represented in the lower section with the slowest growth.

The growth of chub in the Úpoř brook is very slow in comparison with other localities (Leontovyč, 1974; Hanel, 1982,1984; Švátora and Pivnička, 1986, 1989; Ünver, 1998; Türkmen et al., 1999) (Figure 11). The condition coefficient belongs to the average values. In 1993–1999 Vlach and Švátora (2000) recorded slightly faster growth of older fish and the condition coefficient was nearly twice higher in that period.

It is possible to find similarities in the growth of dace: balanced growth, gradually decreasing from the 1st age group, the average value of condition coefficient. The comparisons of the growth of dace in the Úpoř brook with other localities (Vostradovský, 1961; Leontovyč, 1980; Hanel, 1984; Švátora and Pivnička, 1986, 1989) are presented in Figure 12. It is noticeable that the growth is average in this locality. The length growth was the same as the growth of dace in this locality in the period 1993–1999 (Vlach and Švátora, 2000) but the condition coefficient was higher in that period.

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