The Effects of Elevated River Discharge on the Downstream Drift of Young-of-the-Year Cyprinid Fishes

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ABSTRACT

Increases in current velocity and water turbidity during elevated river discharge can increase the abundance of drifting fish of particular size, age or taxa. We tested the effect of artificial and natural increases in river discharge on the drift of young-of-the-year (YOY) cyprinid fishes in a European river. Elevated discharge affected neither drift abundance nor size, age, or taxonomic composition of drifting fishes. Elevated discharge was observed exclusively during the day and did not alter water transparency, whereas current velocity increased significantly. This allowed us to separate effect of these correlated factors, and we conclude that, at least in structurally complex habitats, water turbidity rather than current velocity is the causative factor for the cessation of diel periodicity in drift and increases in drift abundance during floods.

INTRODUCTION

River discharge is a fundamental factor influencing survival and the reproductive success of many riverine fishes, particularly those drifting downstream (Mion et al. 1998, Moriyama et al. 1998). Downstream drift of young-of-the-year (YOY) fishes may have significant consequences for individual fitness and population dynamic and is affected by actual hydrological conditions, including river discharge, water level, current velocity and water turbidity (Pavlov 1994, Johnston et al. 1995, Mion et al. 1998, Reichard et al. 2001, 2002a).

We investigated the effect of elevated river discharge on the drift of YOY cyprinid fishes in a European river. Drift abundance often increases with river discharge (Naesje et al. 1986, Pavlov 1994), which was observed to have both positive and negative effects on YOY mortality. High discharge can rapidly transport larval fishes from spawning to nursery habitats and thereby decrease YOY mortality (Moriyama et al. 1998). Conversely, YOY mortality can increase when fishes drift in turbid water during elevated discharge (Johnston et al. 1995, Mion et al. 1998) or are washed out during floods (Harvey 1987, Bischoff and Wolter 2001). In a previous study, we observed that an extensive flood in a lowland river affected the drift abundance of cyprinid fishes, mainly through the cessation of diel periodicity. Drift typically occurred at night, but during the flood, when current velocity and water turbidity increased substantially, drift abundance did not differ between night and day (Reichard et al. 2001). We hypothesized that water turbidity rather than current velocity was the key factor enhancing increased drift abundance. In the present study, we further investigated this assumption.

We compared drift parameters of cyprinid fishes before and during an artificial and a

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natural increase in river discharge in a sub-mountain river. We sampled during a period of elevated water release from a reservoir. We also sampled drifting fishes before and during increasing discharge following heavy rainfall in the catchment area. We investigated the hypothesis that an increase in river discharge increases the drift abundance of YOY fish, causes cessation of diel periodicity, and changes qualitative parameters of the drift. Thus, we directed our attention to (1) changes in physical habitat characteristics of the river, (2) changes in YOY fish drift abundance, and (3) qualitative changes in YOY fish drift (body size, developmental stages, and taxonomic composition of drifting fish).

METHODS AND MATERIALS

Study site

The River Jihlava (Danube basin, Czech Republic) is 185 km long and is a typical European sub-mountain river. River discharge is controlled by the operation of two reservoirs used for water extraction for a nuclear power station (Peňáz et al. 1999), which affected discharge and temperature regimes of downstream sections of the river. At the sampling site (49°04′36′′ E, 16°26′24′′ N, 28 km downstream the reservoirs, 220 m a. s. l.), the river had a regulated summer discharge of 3 to 21 m^3/s (mean 6.4 m^3/s). The stretch used for the present study was inhabited by rheophilic cyprinids (Peňáz et al. 1999). A major tributary, the River Oslava, affects the river discharge at the study site and reduces the effect of peaks in water releases from the reservoir. The width of the river at the sampling site was 40 m and the river bed was not channelized. The maximum depth of the river was approximately 1.2 m. The river bottom was mainly gravel with some sand and pebbles. The river bank had a natural clay character with some cobbles of 10-20 cm diameter for bank reinforcement and was overgrown with grasses, shrubs, and trees. The fish community at the study stretch consisted of at least 20 species, dominated by *Leusiscus cephalus*, *Leuciscus leuciscus*, *Rutilus rutilus*, *Barbus barbus*, *Chondrostoma nasus* and *Gobio gobio* (Kovařík 1997, Peňáz et al. 1999).

Sampling

Drift samples were collected during the period of peak drift (Reichard et al. 2001, 2002a) on 11-13 June and 8-9 July 1999. During each sampling period, samples were taken from nearshore (< 1 m from the shoreline) and midchannel (5-10 m from the shoreline). The depth of the water column at net positions was 55-70 cm during normal discharge increasing to 103 cm during periods of elevated discharge.

We used one drift net at each position (nearshore, midstream) in June. In July one net was positioned in midstream while two nets (bottom and surface) were used nearshore to test vertical differences in drift parameters. The nets had openings of either 0.13 m^2 (June) or 0.12 m^2 (July) and mesh size 0.5 mm. Nets were held in place with iron rods driven into the substrate and positioned in the middle of the water column (June sampling and midstream July sampling) and/or 5 cm below the water surface and above the bottom, respectively (July nearshore sampling).

In June, we sampled two diel periods. Sampling started in the late afternoon on 11 June and continued until the afternoon of the 13 June. In July, one diel period was sampled from the afternoon of the 8 July to the afternoon of the 9 July. Samples were taken approximately every two hours. Nets were placed in the river for no more than 30 minutes to ensure that the nets did not become clogged.

On every sampling occasion we measured water temperature, dissolved oxygen, and illumination with portable meters, water current in the center of the net opening with a mechanical current velocity meter, and water level with a fixed depth gauge. Water transparency was determined using a Secchi disc during daylight. Discharge data were obtained from the River Authority (Watershed Morava), recorded from the Přibice station 22 km downstream.

Sample processing and analyses

Fishes older than YOY were identified and measured on the river bank and then released. All others were preserved in 4% formaldehyde and identified in the laboratory. Developmental stages were determined according to Balon (1975). The body size was measured as standard length (SL) using callipers, although some fish were damaged and could not be measured.

Drift abundance was calculated as drift density - the number of individuals per 1000 m^3 of filtered water (Reichard et al. 2002a). The non-parametric Mann-Whitney *U* test and Wilcoxon paired test were used to compare environmental and drift density data. Body size data were $\log_{10}$ transformed and subjected to an unbalanced ANOVA General Linear Model with two factors - diel period (day, night) and position in stream (nearshore, midstream in June; nearshore surface, nearshore bottom, and midstream in July). As an insufficient number of factor combinations were obtained in July, Main Effect ANOVA instead of Factorial ANOVA was used and interaction could not be calculated. Scheffé tests were used for post-hoc comparisons of least squared means. The effects of increased discharge on SL and age of drifting fish were compared using Student *t*-test and Chi-squared goodness-of-fit test. All means in the text are expressed with ±1 standard error.

RESULTS

Environmental data

In June, water release from the reservoir increased from 2.2 to 13 m^3/s within four hours (from 4.2 to 12.6 m^3/s in <1 hour) during a period of elevated water release from the reservoir. Consequently, river discharge increased from 5 to 11.4 m^3/s at the Přibice gauging station nine hours after release from reservoir. The exact timing of the flood wave at our sampling site is shown as an increase in water level on Figure 1; the time delay was approximately four hours. In July, the study area received heavy rainfall which considerably increased the discharge in the River Oslava (a major tributary of the River Jihlava between the reservoir dam and study site) and consequently increased the discharge and water level at study site. This natural increase was slower than the artificial water release. Judging from the inundation of bankside vegetation, we considered the water elevation higher by 6 cm as elevated discharge. Elevated discharges, both artificial and natural, occurred exclusively during daytime.

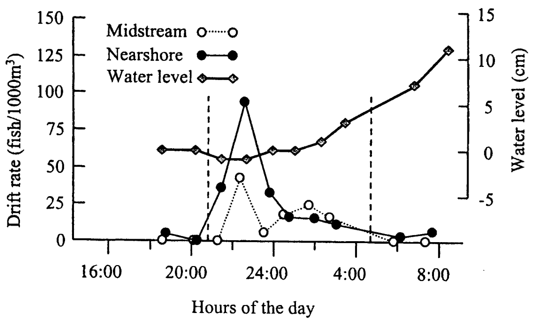

Figure 1. Water level and drift density nearshore and in midstream for samples collected during 11-13 June 1999, with night period (illumination < 5 lux) indicated by dotted vertical line.

Water transparency did not change with elevated discharge (Mann-Whitney *U* test, $n = 13$, $P > 0.05$) and was 20 ±1.6 cm in June and 35 ±0.5 cm in July. Also, water temperature was not affected by elevated discharge (Mann-Whitney *U* test, $n = 21$ and $n = 10$, $P > 0.05$) with a mean value of 15.9 ±0.31 °C in June and 16.6 ±0.12 °C in July. Although dissolved oxygen significantly increased during elevated discharge in June (Mann-Whitney *U* test, $n = 21$, $P = 0.02$), the difference was negligible (9.5 ±0.1 mg/l and 10.3 ±0.3 mg/l respectively). In July, no difference was found (mean 8.5 ±0.2 mg/l).

Water velocity increased significantly during elevated discharges on both dates and all net positions (Table 1). Water velocity varied significantly also between nearshore and midstream both in June and July (Wilcoxon paired tests, $P < 0.05$) and between upper and lower nearshore nets in July (Wilcoxon paired test, $P = 0.02$, Table 1).

Table 1. Comparison of stream water velocities (mean ± SE, m/s) during normal and elevated discharge in relation to net position. Number of measurements (*n*), *Z* value of Mann-Whitney *U* test and its statistical probability (*P*) are indicated.

	Normal Q		Elevated Q		*Z* value	*P*
	n	Mean ±SE	*n*	Mean ±SE		
June						
Nearshore	13	0.45 ±0.006	8	0.56 ±0.030	3.6	<0.001
Midstream	13	0.71 ±0.003	8	1.03 ±0.073	4.0	<0.001
July						
Nearshore lower	8	0.50 ±0.017	2	0.72 ±0.041	2.0	0.025
Nearshore upper	8	0.61 ±0.000	2	0.66 ±0.017	2.7	0.003
Midstream	8	0.78 ±0.013	2	1.01 ±0.000	2.1	0.01

Drift density

In June, elevated discharge during daytime did not cause an increase in fish drift nearshore or in midstream (Mann-Whitney *U* tests, $n = 12$, $P > 0.05$). Nearshore, fishes drifted significantly more at night than during the normal daytime discharge (Mann-Whitney *U* test, $n = 13$, $P = 0.03$) and also during the elevated daytime discharge (Mann-Whitney *U* test, $n = 17$, $P = 0.02$).

Drift density was significantly higher nearshore than in midstream (Wilcoxon paired test, $n = 21$, $P = 0.001$; Fig. 1). Nearshore, the highest drift density was observed during sunset (maximum of 241 fish/1000m^3 and 116 fish/1000m^3 in June and July, respectively), but a different diel pattern was observed in midstream with peaks around midnight (55 and 31 fish/1000 m^3, respectively). Peak drift density in elevated discharge was 102 fish/1000 m^3. No correlation was found between water level and drift density during the daytime (Spearman rank correlation, r = -0.03, n = 12, $P > 0.50$ and r = -0.40, n = 12, $P = 0.20$ for nearshore and midchannel samples, respectively).

For the elevated discharge in July, we obtained insufficient data to test differences in drift densities. However, the data indicate no obvious pattern of increase of drift density with elevated discharge (Fig. 2). Fish tended to drift in the upper strata of the water column in nearshore areas, though this trend was not statistically significant (Wilcoxon paired test, $n = 10$, $P = 0.07$).

Taxonomic composition, fish body size, and developmental stages

We recorded eleven species and one hybrid drifting in the River Jihlava. All drifting fishes were cyprinids with the exception of one *Barbatula barbatula*. Only *R. rutilus* was common in both sampling periods. *L. cephalus* and *L. leuciscus* drifted abundantly only in June (Table 2). No differences in the taxonomic composition of drifting fishes was found between normal and increased discharge.

No effect of elevated discharge on body size composition of drifting fishes was found (Student *t*-test, $n = 31$ and 15, $P > 0.05$). Thus, data from all daytime samples were pooled for further analyses. In June, smaller fish drifted nearshore (12.2 ±0.51 mm SL) than in midchannel (14.7 ±0.99 mm SL) (Factorial ANOVA GLM: $F_{1,148} = 5.9$, $P = 0.016$; Scheffé test: $P < 0.001$). In July, no differences in body sizes of drifting fishes were found (Main effects ANOVA GLM: $F_{2,66} = 0.8$, $P = 0.446$) and mean SL was 19.3 ±1.10 mm.

In June, young larvae dominated drift samples (49%), followed by late larvae (30%) and juveniles (21%) ($n = 159$). In July, young larvae formed only 7%, late larvae 35% and juveniles 58% ($n = 74$). The proportion of developmental stages in the drift did not differ between normal and elevated discharge (Chi-squared test, $df = 2$, $P > 0.05$). Fishes older than YOY were rarely captured in drift nets. Those that were captured were mainly *G. gobio*.

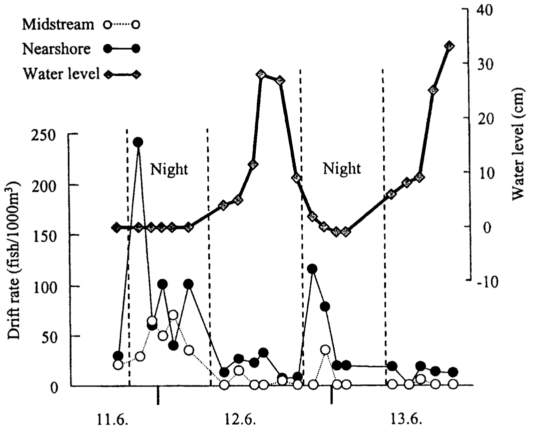

Figure 2. Water level and drift density nearshore (upper and lower nets combined) and in midstream in 8-9 July 1999, with night period (illumination < 5 lux) indicated by dotted vertical line.

DISCUSSION

The most powerful effect of elevated discharge on the downstream drift of YOY fishes is during the primary pulse. Harvey (1987) observed that most YOY cyprinids and centrarchids drifted during the first five hours (from 17:00 to 22:00) of a flood in a small Oklahoma stream (normal discharge of 0.03 m^3/s) and that flooding caused a disappearance of all cyprinids less than 10 mm. In that study, larger cyprinids also drifted, although to a considerably lesser extent. We did not find any short-term effect of elevated discharge on YOY fish drift parameters, although YOY cyprinids less than 10 mm were present in the river during our study. Elevated discharge neither increased drift abundance nor caused drift of a particular taxonomic, size, or age category.

Most fishes drifted at night and no substantial increase in discharge was observed at night during the present study, and thus we were not able to quantify the effect of elevated discharge on nocturnal drift. However, we showed previously that a 12-fold rise in river discharge did not increase the nighttime drift abundance of cyprinid fishes (Reichard et al. 2001) but did cause a cessation of diel periodicity, with fish drifting abundantly during the day. Consequently, we suggested that water transparency rather than higher water velocity was the key factor enhancing fish drift during the day. Conditions during the present study allowed us to further investigate this hypothesis. We found that elevated discharge did not alter water transparency and did not increase drift abundance during the day. Thus, increased stream water velocity itself is not the causative factor related to increase in drift abundance and cessation of diel periodicity during high discharge, at least over the river discharges we investigated. The effect of high water turbidity is a more plausible explanation because cyprinid larvae use visual cues for orientation (Pavlov 1994) and drift at night (Reichard et al. 2002b) and in turbid water (Reichard et al. 2001), possibly to avoid visually feeding predators by drifting when water visibility is reduced (Flecker 1992).

Drifting fishes are known to respond differently to elevated river discharge. We believe that the observed differences mirror distinct ultimate cues for drifting. In migratory fishes, high discharge promotes rapid migration and increases survival (Moriyama et al. 1998) and drift abundance and river discharge were strongly positively correlated in coregonid and salmonid species (Naesje et al. 1986, Johnston 1997). In contrast, drift abundance depended on factors other than river discharge in non-migratory fishes (Reichard et al. 2002a) and, with the exception of major floods, no correlation between river discharge and drift abundance was found in catostomid and cyprinid fishes (Robinson et al. 1998, Carter and Reader 2000, Reichard et al. 2002a). However, Bischoff and Wolter (2001) reported a drastic decline in YOY cyprinid abundance after an extensive summer flood, and Harvey (1987) observed a considerable increase in passive drift during an erosive flood. We believe that indirect effects, such as low food supply, oxygen depletion or gill damage from suspended sediments (Mion et al. 1998), rather than high current velocity, may cause the larval mortality observed during elevated discharges in structurally complex rivers (Bischoff and Wolter 2001, Jurajda and Reichard unpublished data), and these effects can manifest themselves later in the flood. The higher impact of floods in habitats with poorly structured banks has been observed (Bischoff and Wolter 2001), and increased water velocity alone can induce passive washing out of YOY fish if habitat complexity is low and flow refuges for fish are scarce (Harvey 1987). YOY fishes were able to move into flooded vegetation along the shoreline with minimal flow which served as refuges from passive drifting in the present study.

Table 2. List of species caught in drift samples in the River Jihlava in June and July 1999. Number of fish caught (*n*) and their relative abundance (%) are shown for both dates combined (Total) and for individual sampling periods.

Common name	Scientific name	Total		June	July
		n	%	*n*	*n*
Roach	*Rutilus rutilus* (L.)	83	35.6	44	39
Chub	*Leuciscus cephalus* (L.)	61	26.2	52	9
Dace	*Leuciscus leuciscus* (L.)	27	11.6	26	1
Nase	*Chondrostoma nasus* (L.)	21	9.0	6	15
Barbel	*Barbus barbus* (L.)	15	6.4	11	4
Gudgeon	*Gobio gobio* (L.)	6	2.6	4	2
Japanese minnow	*Pseudorasbora parva* (Schlegel)	6	2.6	5	1
Bleak	*Alburnus alburnus* (L.)	3	1.3	1	2
Carp	*Cyprinus carpio* L.	3	1.3	3	
Bitterling	*Rhodeus sericeus* (Pallas)	1	0.4		1
Stone loach	*Barbatula barbatula* (L.)	1	0.4	1	
Hybrid	*L. cephalus* × *C. nasus*	1	0.4	1	
Unidentified cyprinid		5	2.1	5	
Total		233		159	74

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