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Letter

Do small tributaries function as refuges from floods? A test in a salmonid-dominated mountainous river

Itsuro Koizumi[1], Koh Hasegawa[2], Daisuke Kishi[3]
[1]Creative Research Institution, Hokkaido University, Sapporo, Japan
[2]Hokkaido National Fisheries Research Institute, Fisheries Research Agency, Sapporo, Japan
[3]Gero Branch, Gifu Prefectural Research Institute for Freshwater Fish and Aquatic Environments, Gero, Japan

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Tributary streams are important for freshwater fishes, providing rearing, spawning and overwintering habitats (Northcote 1997). Tributaries may also function as temporal refuges from floods or droughts. Fisherman's anecdote often says that many large fishes were unexpectedly caught in small tributaries during floods, presumably because of immigrants from the main stem. Despite the plausibility, surprisingly few studies have examined the hypothesis, and limited observations rather showed weak evidence (Harvey et al. 1999; Han et al. 2007). As far as we know, a positive result was shown only by Nunn et al. (2010) in a floodplain tributary in a cyprinid-dominated lowland river.

On 8–10 August 2003, a powerful typhoon hit Hokkaido Island, Japan, accompanied with heavy rain, which allowed us to investigate the potential role of tributaries as refuges from flooding. We had just completed annual population census in four small tributaries of a river system 1–2 days before the typhoon. Thus, we planned additional census in the same manner in the four tributaries on 13–14 August (i.e., 3–4 days after the typhoon). This river system is ideal to examine fish movements between tributaries and the main stem because immigrants can be distinguished because of large differences in fish species and size structures between the two habitats.

The censuses were taken place at the Shiisorapuchi River, one of the major branches to the Sorachi River that drains into the Kanayama Reservoir in a mountainous area of central Hokkaido (43°10′N; 143°30′E). This river system consists of a large number of small tributaries that drain directly to the larger main stem. Environments in the tributaries and the main stem differ markedly, such as stream size (0.5–3.0 m in width, 0.01–0.5 $m^3 \cdot s^{-1}$ in water discharge for tributaries; 5–30 m in width, 1.0–10 $m^3 \cdot s^{-1}$ in discharge for the main stem) and dominant substrates (sand to cobble for tributaries, boulder to bedrock for the main stem) (Koizumi & Maekawa 2004; Koizumi et al. 2006, 2008).

Rainfall brought by the typhoon in the study area was 134 mm on 9 August 2003, the fourth highest daily record since 1977 (i.e., 8–10 years recurrence interval, data from the Japan Meteorological Agency). Precipitation accumulated to 195 mm during 8–12 August. Hourly peak flow in the main stem near the Kanayama Reservoir was >250 $m^3 \cdot s^{-1}$, more than 30 times higher than the days before the typhoon (data from the Ministry of Land, Infrastructure and Transport, Japan). Although water discharge was not monitored in small tributaries, the disturbance looked much less severe: stream flow in the main stem was violent and muddy brown, whereas those in tributaries were much milder and did not turn brown (I. Koizumi, personal observation).

In the four small tributaries (named T10, T13, T20 and T54), single-pass electrofishing was conducted throughout the whole streams, that is, from the junction of the main stem to the headwaters (T54 was censused from the junction to just below an impassable erosion control dam; no fish exist above the dam) by using a backpack electrofisher (Smith-Root Inc., Vancouver, WA, USA). The distances censused in the four tributaries ranged from 91 to 145 m with mean stream widths from 1.0 to 1.2 m and

Correspondence: I. Koizumi, Creative Research Institution, Hokkaido University, N21W10 Sapporo, Hokkaido 001-0021, Japan. E-mail: itsuro@cris.hokudai.ac.jp

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mean depths from 5.8 to 9.3 cm. The capture probability by electrofishing is high in this kind of small tributaries (e.g., Koizumi et al. 2008). In addition, because the same person (I. Koizumi) electrofished in the same manner in each census, we assumed the one-pass electrofishing yielded useful values to compare the relative abundances before and after the flood. In fact, the correlations between population estimates from three-pass electrofishing removal method and the number of individuals caught in the first pass are very high in this kind of small tributaries ($r > 0.9$, I. Koizumi, unpublished data). Small fishes (<20 mm) were not included in the analysis because of the difficulty in collecting such individuals. In T54, some age-0+ charr were difficult to identify (Dolly Varden *Salvelinus malma* or white-spotted charr *S. leucomaenis*) because of small size and the possibility of hybridisation (I. Koizumi, unpublished data). Therefore, such individuals were treated as Dolly Varden in the analysis. Fish fauna and size structures in the main stem were surveyed near the junctions of each tributary (within 250 m reaches from the junction) on 11–13 August 2011. Electrofishing was mainly used, complimented with cast net, fishing and snorkelling (snorkelling was performed by the same person, I. Koizumi, for standardising the data). Although the survey in the main stem was not so quantitative and the year of the survey was different, the data should be enough to represent the fish fauna and size structures in the main stem. Fish captured were anaesthetised with 2-phenoxy-ethanol and measured to the nearest 1 mm (fork length for salmonids, total length for other species). Fish seen by the underwater snorkelling was estimated nearest 10 mm by using the objects near the individuals as references, such as particle substrates and twigs (i.e., measured the objects instead of the fishes).

Before the typhoon, all the tributaries were dominated by small (<100 mm) Dolly Varden with 5–10 individuals of relatively large (100–149 mm) Dolly Varden (Table 1). Small numbers of white-spotted charr and freshwater sculpin *Cottus nozawae* were also present in some of the tributaries. No individual exceeded 150 mm in the tributaries before the flood. On the contrary, fishes larger than 150 mm were commonly observed in the main stem (Table 1). Moreover, in addition to the three species above, Sakhalin taimen *Hucho perryi*, Japanese/rosyface dace *Tribolodon* spp. and Siberian stone loach *Barbatula barbatula toni* were present in the main stem. Therefore, the presence of large fish or the presence of the latter three species in the tributaries during floods should be the evidence for the use of tributaries as refuges.

After the typhoon, however, fish species and size structures in the tributaries did not change remarkably. Although the numbers of small individuals (<100 mm) decreased in all the tributaries, probably due to being washed out by the flood, those of larger fishes remained stable. The only one fish (Dolly Varden in T10) larger than 150 mm was observed after the flood. In this tributary, the number of Dolly Varden in the size class 100–149 mm also increased slightly (from nine to 13 individuals), suggesting immigration from the main stem during the flood. Another potential

Table 1. Number of individuals and size structure of fishes observed in four tributaries before and after the flood and those in the main stem (MS) near each tributary.

	Dolly Varden charr			White-spotted charr			Sakhalin taimen			Freshwater sculpin			Siberian stone loach			Japanese/rosyface dace		
	MS	Before	After	MS	Before	After	MS	Before	After	MS	Before	After	MS	Before	After	MS	Before	After
T10 (mm)																		
<100	4	170	80	12	0	0	0	0	0	76	0	1	0	0	0	0	0	0
100–149	34	9	13	23	0	0	0	0	0	38	0	3	1	0	0	0	0	0
150–299	25	0	1	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>300	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0
T13 (mm)																		
<100	8	90	65	6	0	14	0	0	0	58	2	2	0	0	0	0	0	0
100–149	22	6	7	30	0	0	0	0	0	10	0	1	1	0	0	0	0	0
150–299	17	0	0	22	0	0	0	0	0	1	0	0	0	0	0	0	0	0
>300	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
T20 (mm)																		
<100	16	385	227	12	8	14	1	0	0	58	2	0	0	0	0	0	0	0
100–149	41	5	4	31	0	0	0	0	0	22	0	0	25	0	0	0	0	0
150–299	13	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>300	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
T54 (mm)																		
<100	0	75	23	1	14	8	20	0	0	36	3	5	0	0	0	0	0	0
100–149	0	10	8	11	0	0	0	0	0	9	1	3	1	0	0	1	0	0
150–299	5	0	0	36	0	0	0	0	0	0	0	0	1	0	0	14	0	0
>300	0	0	0	6	0	0	1	0	0	0	0	0	0	0	0	0	0	0

immigration from the main stem was small (<100 mm) white-spotted charr in T13 (from zero to 14 individuals) and T20 (from eight to 14 individuals) and <150 mm freshwater sculpin in T10 (from zero to four individuals) and T54 (from four to eight individuals). No timen, dace or loarch was detected in the tributaries, nor white-spotted charr larger than 100 mm that were abundant in the main stem near the tributaries.

Overall, our results did not support the hypothesis that many large fishes immigrate to small tributaries during floods. Radio-telemetry studies revealed that stream fishes can have remarkable tolerance to catastrophic floods by using micro-refuges, such as large woody debris, boulders or stream margins (Harvey et al. 1999; Makiguchi et al. 2009). Because large particle substrates are abundant in the main stem in the Shiisorapuchi River and the river has floodplain areas, enough refuges might have existed even in the main stem during the heavy flood. In addition, despite the apparent disturbance, the flood caused by the typhoon might not have been catastrophic for fishes, considering only 10 years recurrency. Tributary habitats might become refuges only during more severe floods. Alternatively, fishes may use tributaries only in the situations where not enough micro-refuges in the main stem are available. Given that the frequency of severe floods may be increasing worldwide because of climate change (Groisman et al. 2005), understanding conditions under which fishes escape into small tributaries during floods would become more important.

We, however, cannot exclude the possibility that the time scale fishes reacted the disturbance may be more rapid compared with our sampling period. If fishes used tributaries just during the peak flow and immediately went back to the main stem, our survey cannot reveal the escaping behaviour. Although our pre- and postflood comparison was conducted exceptionally within a narrow time-frame, even this may not be enough to detect the escapement from the main stem. Although it is dangerous and logically difficult, surveys during flooding should be favourable.

Despite the lack of evidence of mass movement, our result suggested a few immigrants from the main stem (i.e., juvenile white-spotted charr, sculpin and a few relatively large Dolly Varden). Because more than 100 small tributaries exist in the Shiisorapuchi River (Koizumi 2011), only a few individuals escaping to each tributary should accumulate to a great number enough to re-colonise main stem habitats even if fishes in the main stem were extirpated. Multiple refuges at different spatial scales should increase resistance and/or resilience of fish populations (Sedell et al. 1990; Pearsons et al. 1992). Thus, the roles of tributaries as refuges would deserve further attention.

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