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Report

Rediscovery of Japanese charr in the Denjogawa River and its tributary in 2016 after a disturbance from the Ontake Landslide in 1984: significance of a tributary as a refugium from disturbance

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Abstract

Japanese charr (*Salvelinus leucomaenis japonicus*) was rediscovered in Denjogawa River and its tributary in 2016 against reports of its extinction following huge sediment inflows caused by the Ontake Landslide associated with the Western Nagano Prefecture earthquake in 1984. All of the 27 individuals of the charr were observed in pools more than 30 cm deep. Most (25 of 27) of the fish were observed in the tributary, and relative density (represented as count per unit effort [CPUE]) was higher at upstream sites in the tributary. Moreover, the fish in the tributary had wider ranges of body size. In Denjogawa River, the species was observed downstream of the confluence but not upstream although both sites had pools of depths more than 30 cm. As relative density gradually decreased from upstream of the tributary to downstream of the confluence, the population in the tributary should be considered as the source population. Furthermore, the population in the Denjogawa River should have been maintained by the individuals drifting from the tributary. Additionally, the wide ranges of the body size of fish in the tributary suggest that the population in the tributary was maintained through reproduction. Because the small population in the tributary may function as a source population for that in the Denjogawa River, it will be significant to secure migration pathways between the mainstream and the tributary for continuity of the population in the Denjogawa River system.

Key words: mountain stream, disturbance regime, refugia, Mt. Ontake, the Western Nagano Prefecture earthquake

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Introduction

As mountain rivers tend to undergo massive disturbances such as from landslides due to high gradient, habitats of fishes in the rivers tend to be unstable and fail to sustain their populations (Geertsema *et al*., 2009). However, mountain rivers have many tributaries (Horton, 1945; Allan, 1995), which can function as refugia from such disturbances (Sedell *et al*., 1990; Koizumi *et al*., 2013). Accordingly, monitoring of the recovery processes of the fish population after disturbances is significant for understanding the mechanisms that sustain fish populations in these rivers. Nevertheless, such monitoring is difficult because massive disturbances sometimes cause extinction of fish populations and because records of changes in fish population are scarce. Fortunately, I had the rare opportunity of finding a population of the Japanese charr (*Salvelinus leucomaenis japonicus*), which had been reported to be extinct in the Denjogawa River system after the Ontake Landslide caused by the Western Nagano Prefecture earthquake in 1984 (Takeda, 1985). As the population was found about the confluence of the Denjogawa River and a tributary, this provides opportunities to examine the significance of tributaries for resilience of the fish population in the mountain rivers. In this study,

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the significance of the tributary for resilience of fish population was evaluated by comparing fish density and size distribution among sites around the confluence.

Methods

Japanese charr was searched at five sites located near the confluence of the Denjogawa River and a tributary located on the southern side of Mt. Ontake in central Japan (Figs. 1 and 2A). The watershed areas of the Denjogawa River and the tributary were estimated at 8.52 and 1.95 km^2, respectively, by a spatial analyst tool (hydrological analysis) (ArcView 10.2; ESRI Japan) using fundamental geospatial data from Geospatial Information Authority of Japan as digital elevation model (DEM) data (T. Tashiro, unpublished data). Water quality were measured in the Denjogawa River (electrical conductivity: 41.40 mS m^{-1}, water temperature: 14.1 °C, pH: 7.5, turbidity: 0.36 NTU, and chromaticity: 1.54) and the tributary (ibid. 2.30 mS m^{-1}, 12.8 °C, 6.8, 0.17 NTU, and 2.62, respectively) at 11:00 and 12:45 h on September 15, 2016, respectively (K. Nozaki, unpublished data). Each site was chosen to include one or more pools with a depth greater than 20 cm, which is preferred by the charr (Yagyu, 2009) and considered as potential habitat of the fish. All the sites were separated by placing weir(s), except between sites 2 and 5 (Fig. 1B).

Fish censuses were performed at all sites on September 15 and 16, 2016, by snorkeling for 15 or 30 min according to the observed fish density. The fish species was identified under water as *Salvelinus leucomaenis japonicus* based on the patterns of colors and spots (Nakabo, 1993). Because adults of the subspecies *S. l. pluvius* were absent, young fish with white spots on the sides of body but not on their back or vertex of the head were also identified as *S. l. japonicus*, moreover (Naruse and Yoshiyasu, 1983). The size distribution was approximated by measuring the total length of the fish to the nearest multiple of 5 cm by visual estimation, corrected using a ruler under water. The numbers observed were divided by the searching times to convert counts into relative density as counts per unit effort (CPUE), according to the method described by Onoda and Kayaba (2016).

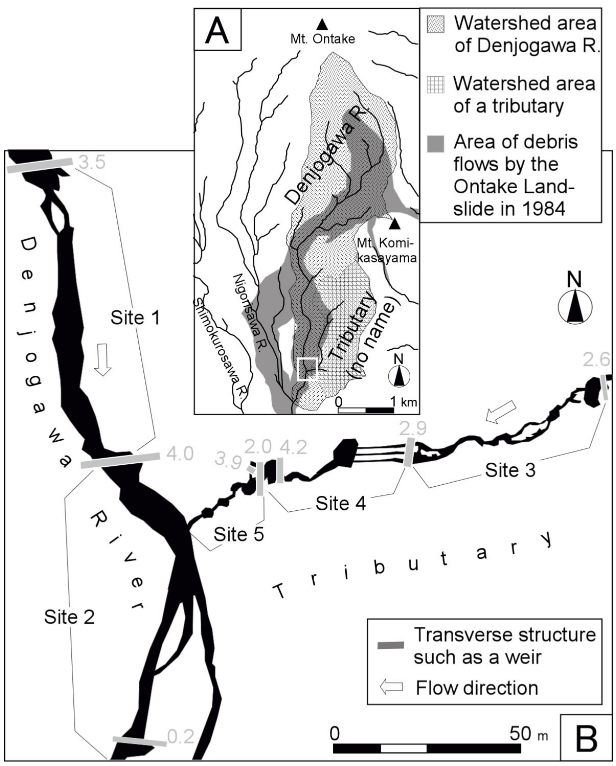

Fig. 1. Location of the Denjogawa River and a tributary (A), and study sites around the confluence (B). Fig. 1B gives an enlarged view of the inset in Fig. 1A. Area that had received debris from the Ontake Landslide in 1984 is redrawn in gray, according to Mizuyama and Hara (1991). Each number (gray) near a transverse structure in Fig. 1B indicates its height (in meters) from the water surface of the site immediately downstream to it.

Results

A total of 27 individuals belonging to one taxon (Japanese charr, *Salvelinus leucomaenis japonicus*) were observed in this study (Table 1, Fig. 2B, C, D). Relative density (CPUE) ranged from 0 to 14 individuals per 30-min observation and decreased gradually along the tributary from upstream to its confluence with the Denjogawa River. In the Denjogawa River, some fish were present at the downstream site (site 2) but not at the upstream site (site 1). The body size distribution of the fish was wider at the sites in the tributary than in the Denjogawa River (Table 1). Noticeably, among all the sites, the body size distribution of the fish was widest (range: 10–30 cm) at the most upstream site of the tributary (site 3).

Discussion

Possibility of survival of the charr population after a large disturbance

The fish populations observed in this study might have survived a large-scale disturbance (*i.e*., the Ontake Landslide in 1984). This possibility is supported by some collateral evidences. First, all the observed fish were identified as

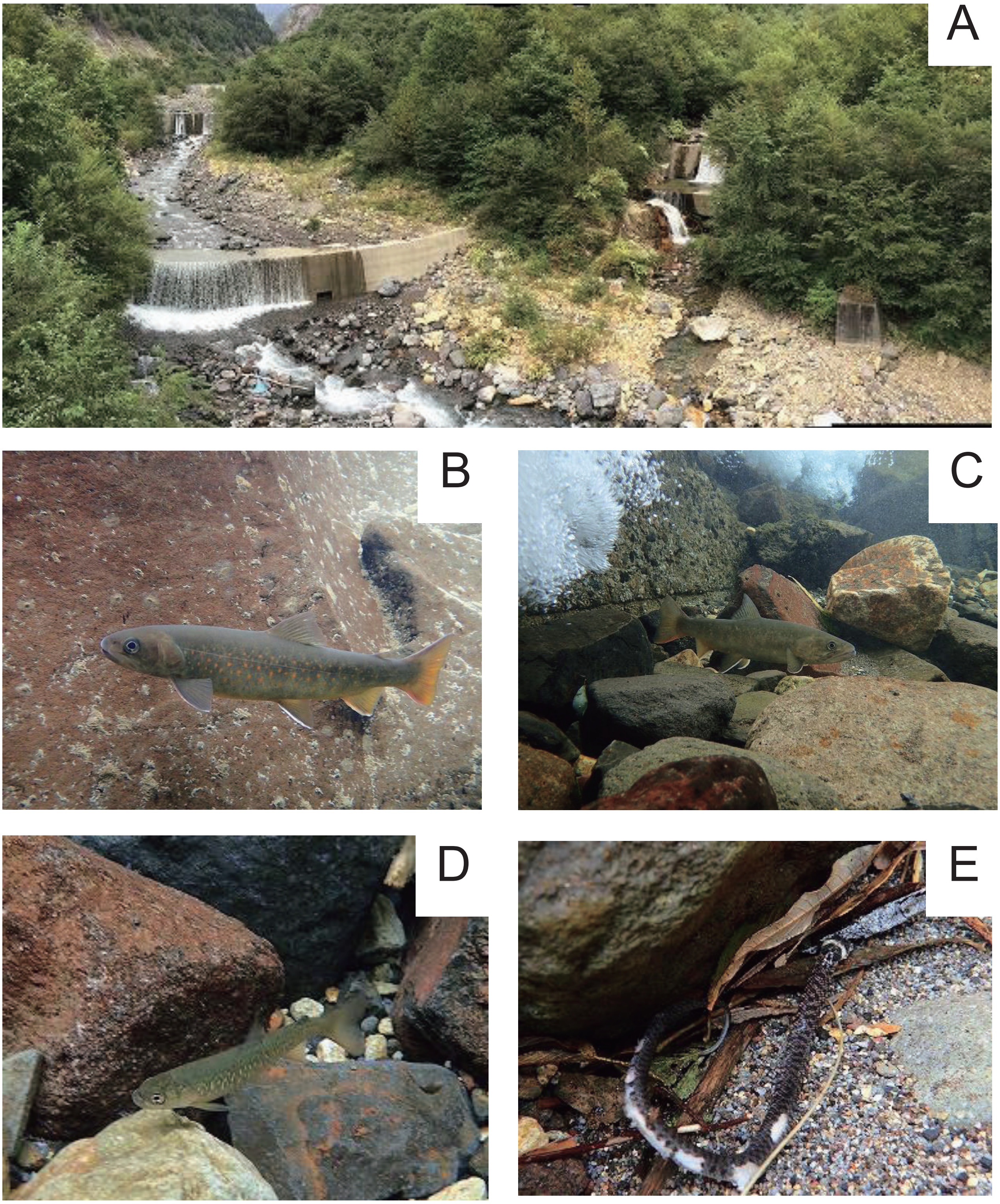

Fig. 2. Photographs of the study sites near the confluence (A), adult (B, C) and young (D) of Japanese charr, and a dead small snake (*Rhabdophis tigrinus*) with some bite marks (E). The Denjogawa River (left) and the tributary (right) meet near the mid-bottom of the photograph (A). The photograph (A) was taken by T. Tashiro and the other photographs (B-E) were taken in pools of the tributary by the author.

Table 1. List of observed fish at the sites in the Denjogawa River and its tributary.

Site no.[*1]	Observation		Species	Total body length (cm)	Observed fish		Maximum depth (cm)[*3]
	Date in 2016	Time (min)			number	CPUE[*2]	
Denjogawa River							
1	Sep. 16	15			0	0	55
2	Sep. 15	15	*Salvelinus leucomaenis*	20	1	2	70
				10	1	2	70
Tributary							
3	Sep. 16	30	*Salvelinus leucomaenis*	10	4	4	90
				15	3	3	90
				20	2	2	90
				25	4	4	90
				30	1	1	90
4	Sep. 15	30	*Salvelinus leucomaenis*	10	3	3	120
				25	3	3	120
				30	1	1	120
5	Sep. 15	30	*Salvelinus leucomaenis*	10	1	1	30
				15	1	1	70
				25	2	2	70

[*1] Detailed information of the sites is presented in the text and in Figure 1. Table 1. Fish observed at the sites in the Denjogawa River and its tributary.
[*2] Counts per unit effort
[*3] Maximum depth of the pool where fish were observed or searched.

Salvelinus leucomaenis japonicus, a species that was distributed in the Denjogawa River before the landslide in 1984 (Takeda, 1985). Second, artificial release of the fish in the Denjogawa River is not known since the landslide occurred (Y. Sawada, personal communication). Moreover, cultivation of the species is known to be much less preferred than that of the subspecies *S. l. pluvius* (Tsuchida *et al*., 2008), suggesting that the observed fish could not have been released. Third, according to aerial photographs taken after the landslide, the tributary studied seems to be located on the margin of a range of the landslide (T. Tashiro, unpublished data, also see Fig. 1B). Given with the above information, the fish population found in this study is likely to have survived the disturbance caused by the landslide, although the possibility that the fish were artificially released should be considered carefully.

Maintenance of the local population of the charr in the tributary through reproduction

Even if the observed population of charr consisted of released individuals, it is noteworthy that the population has maintained itself through reproduction. The population in the tributary had a wider range of body sizes (10–30 cm), which are equivalent to the body size of one- (body length: 13–16 cm), two- (16–22 cm), and three-year fish (17–25 cm), respectively (Miyadi *et al*., 1976). Of them, larger charrs, corresponding to two and three years of age, are known to reproduce (Miyadi *et al*., 1976). Yamamoto *et al*. (1994) reported reproductive activity in male and female charr that had body lengths of more than 17 and 21 cm, respectively, based on gonado somatic index (GSI). Similarly, Kitano *et al*. (2005) found reproductive activity in male and female charr that had fork lengths of more than 20 and 22 cm, respectively. Additionally, the charr intrinsically prefer tributaries to mainstreams as habitats for reproduction (Nakamura, 1999). Furthermore, the entire watershed area of the tributary (1.95 km^2) is larger than 1.01 km^2, which is needed to maintain charr populations (Endou *et al*., 2006) although the effects of fragmentation on the population by weirs in the tributary should also be discussed circumstantially in future studies. Therefore, the wide ranges of body size in the tributary suggest that the population has been maintained through reproduction.

Significance of local population in the tributary as a source population

This study suggests that local population in the tributary functions as a source population in the Denjogawa River because relative density decreased along the tributary and the confluence (Table 1). A higher density in the tributary might be caused by the migration for reproduction from the mainstream, because this study was performed in the early reproductive season of the charr (late September to early November, Miyadi *et al*., 1976). However, the fish are unlikely to have migrated upstream in the tributary because high weirs existed between the study sites (Fig. 1B) and the charr could migrate only downstream in the tributary. As the upper site in the Denjogawa River had no charr, the possibility that the charr population in downstream site of the Denjogawa River being caused by a drift from upstream is quite unlikely. Therefore, the charr population in the mainstream of the Denjogawa River is likely maintained by the charrs provided by the tributary.

Implications for conservation of sustainable population of the charr

It is important to secure the Denjogawa River and its tributaries to allow re-colonization and conservation of a sustainable charr population in the Denjogawa River system. Although the studied tributary is expected to have a watershed area larger than that necessary for the sustainability of the charr population, the usable area for the population may have decreased by isolation due to transverse constructions such as weirs (Endou *et al*., 2006). A decrease in the usable area should mean a decrease in the carrying capacity. Indeed, a dead small snake (*Rhabdophis tigrinus*) with bite marks, assumed to have been received from a charr (Miyadi *et al*., 1976), was found in a pool of the tributary (Fig. 1E), likely reflecting severe shortage of prey resources in the small tributary. As the re-colonization by the charr population increases usable area and the carrying capacity at the watershed scale, it should contribute to conservation of the sustainable population. Additionally, the re-colonization will act to disperse the risks encountered during the next disturbance because the tributary, which functioned as a refugium in this event, might actually receive greater disturbances, such as landslides, in the next event. Moreover, the re-colonization can resolve the isolation, which causes decrease in genetic diversity (Morita *et al*. 2009). Therefore, securement of the pathways for migration and re-colonization will be significant to improve the resilience of the metapopulation. Changes in the charr population of the Denjogawa River system, including its tributaries, should be surveyed continuously and extensively in further studies to comprehensively understand the effects of tributaries as refugia and the recovery processes from huge disturbances such as landslides.

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摘　要

1984年に発生した御嶽崩れ（山体崩壊）による撹乱後の伝上川とその支流における2016年のヤマトイワナの再発見：撹乱からの避難場所としての支流の重要性

小野田幸生

王滝川水系の伝上川では，1984年の長野県西部地震に伴う御嶽崩れ（山体崩壊）による土砂流入によって，ヤマトイワナの個体群が絶滅したと報告されていた。しかしながら，2016年9月末に潜水目視調査によって，イワナ属魚類が27個体発見された。確認された地点は水深が30 cm 以上の落ち込み型の淵であった。確認個体の多くは，伝上川の左岸に流入する支流で確認され，上流ほど単位努力量当たりの確認個体数が多かった。伝上川本川では水深が30 cm 以上の淵があったにも関わらず，支流の合流点の下流側では2個体が確認され，上流側では確認されなかった。多くの調査地点の間に治山ダムがあることを合わせて考慮すると，調査対象の支流がソース個体群であり，流下した個体群が伝上川で確認されたと考えられる。さらに，伝上川本川と比べて，支流の個体群の体サイズは幅広いサイズで構成されたことから，支流の個体群は再生産を通じて維持されてきたと考えられる。支流などを単位とした局所個体群は小規模であるため，他の個体群との交流が確保されるような移動を保障することが，山地河川に生息するイワナの保全に重要であると考えられる。

キーワード：山地河川，撹乱体制，避難場所，御嶽山，長野県西部地震