Changes in gut contents of Japanese dace accompanying with sediment addition using the sediment bypass tunnel of Koshibu Dam

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Abstract

Shifts in the diets of omnivorous fishes can be a useful indicator of the effects of sediment addition through sediment bypass tunnels on food chain structure. Therefore, we analyzed the main gut contents of an omnivorous fish, Japanese dace (*Tribolodon hakonensis*) in an impacted river in central Japan (the Koshibu River) before and after the sediment addition through the sediment bypass tunnel of Koshibu Dam and compared the results with those in a reference river (the Toyama River), which has no large dams. In the impacted river, the gut contents mainly comprised algae before the sediment addition but were dominated by aquatic insects after the addition, whereas in the reference river, the gut contents mainly comprised aquatic insects throughout the study period. This shows that the main gut contents of the fish in the impacted river became similar to those in the reference river following the sediment addition. Therefore, the results suggest that the changes in the diet caused by sediment addition should be considered as a positive effect although the mechanism that caused this diet shift remains to be examined.

Keywords: sediment bypass tunnel, diet shift, omnivorous fish, comprehensive sediment management

1 Introduction

Artificial sediment addition can alter the sediment regimes in rivers; thus, it is important to assess whether any impacts would be occurred. Effects of artificial sediment addition from dams have previously been examined for specific taxa, such as algae, aquatic insects, and fishes. The previous study showed that algae were more easily detached from stones when a flushing flow was combined with sediment addition (Sakamoto et al. 2005), resulting in the recovery of downstream sites from algal overgrowth. Furthermore, although macroinvertebrate assemblages downstream of dams mainly comprised species that prefer coarse and armored riverbeds, such as net-spinners (Hatano et al. 2005), some macroinvertebrates that favor fine sediment were recovered by sediment addition (Awazu et al. 2015). In addition, reproduction habitats of some fishes were created by “fresh” sediments (with hardly any algae) accompanied by sediment addition (Kajino et al. 2003). Thus, artificial sediment addition through sediment bypass tunnels can improve the conditions and habitats of some taxa because the addition occurs alongside high flow, mimicking natural conditions.

Where sediment addition recovers particular taxa, its effects may be propagated to higher trophic levels, such as fish. For example, changes in algae and macroinvertebrate communities can alter the type and abundance of food available to fish. In addition, changes in the physical environment that accompany artificial sediment addition through sediment bypass tunnels may alter the feeding efficiency of prey organisms, such as attached algae and aquatic insects, thereby changing the feeding habitat of fish and leading to a shift in the prey that are taken. Such a shift would be particularly likely to occur in omnivorous fishes because they are able to use both algae and insects. Thus, the effects of sediment addition through sediment bypass tunnels on ecosystem functions, such as food webs, can be detected by monitoring the prey use of omnivorous fishes. However, no previous studies have examined this aspect.

Here, we evaluated the effect of artificial sediment addition on the food chain structure by examining whether the omnivorous cyprinid fish Japanese dace (*Tribolodon hakonensis*) shifted its prey use as a result of sediment addition through the sediment bypass tunnel of the Koshibu Dam in the Koshibu River, central Japan. We analyzed the main gut contents of fish inhabiting sites downstream of the dam before and after sediment addition and compared to those of fish inhabiting a reference river with no large dams. In addition, we monitored the prey abundance and feeding conditions in both rivers.

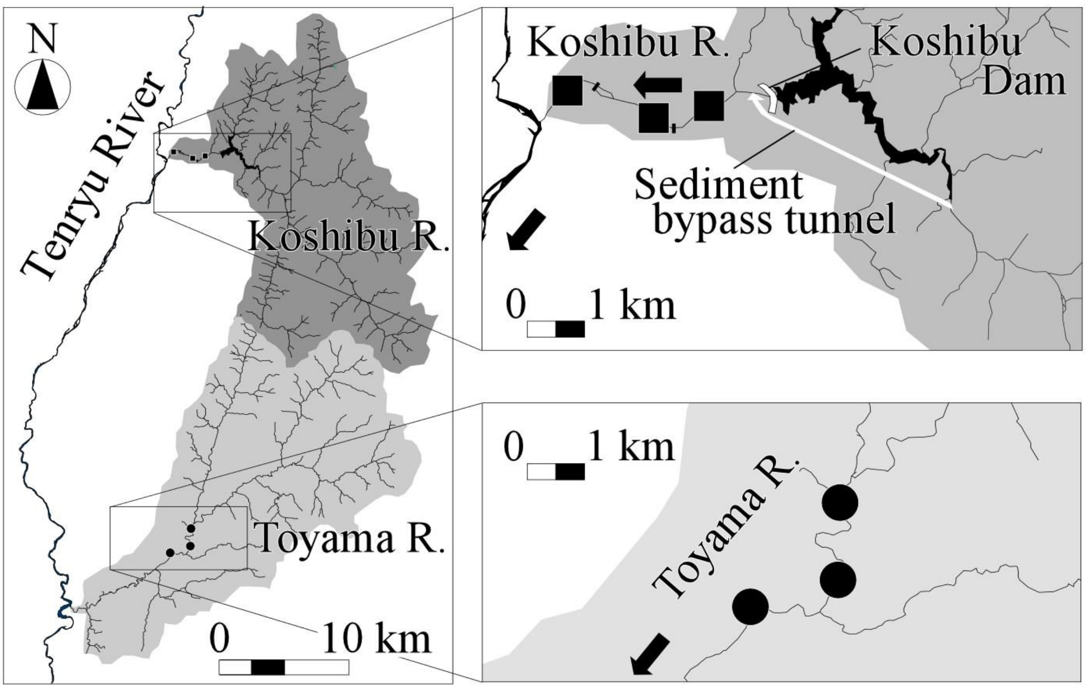

Fig. 1 Locations of the six study sites. Squares and circles indicate the study sites in the Koshibu and Toyama Rivers, respectively, while dark and light gray areas indicate the drainage areas in each river. White and black arrows indicate the sediment bypass tunnel of the Koshibu Dam and the flow direction in the rivers, respectively.

2 Methods

2.1 Study sites

Six study sites were established in Nagano Prefecture, central Japan (Fig. 1). Three of these sites were designated as impact sites and were located downstream from the outlet of the sediment bypass tunnel (completion year: 2016, purpose: sediment discharge, cross-section shape: horseshoe shape [2r = 7.95 m], length: 3,999 m, longitudinal slope: 2.00%) of the Koshibu Dam in the Koshibu River. Sediment addition through the tunnel has been started since September 2016. The remaining three study sites were designated as reference sites and were located in the middle reaches of the Toyama River with no large dams. Each the three sites were set to have a similar drainage area.

2.2 Data collection

Fish surveys were conducted in June, September, and October 2016, with the first two survey periods corresponding to pre-surveys and the final survey period corresponding to a post-survey after the sediment addition through the sediment bypass tunnels of Koshibu dam in 2016. Fish were caught using an electro-fisher (LR-24; Smith-Root, Inc.) and scoop and brail nets, and were anesthetized in ca. 0.02% FA-100 solution (Tanabe Seiyaku, Osaka, Japan). The body size of each fish was measured to the nearest mm and the gut contents were collected using the stomach pump method (Kamler and Pope 2001) and then fixed in a vial containing 10% formalin solution, using a separate tube for each individual. Gut contents were not collected from small fish (total length < ca. 65 mm) because their mouth was too small to accept the smallest plastic dropper (2 ml) as a stomach pump. The stomach pump method was selected for continuous surveys because the fish density was not particularly high at the study sites. All of the caught fish were released to their collection site following recovery.

The main gut content of each sampled fish was determined by estimating the most abundant volume in three categories of food (aquatic insects, algae, and others) in a laboratory of Aqua Restoration Research Center in Gifu Prefecture, central Japan. The results were then integrated for each sampling period and river. When two or all three of these categories had the same volume abundance in a sample, we divided the result by the number of categories and then integrated the data.

The abundances of attached algae and aquatic insects were also quantified as these represent prey resources. To sample the attached algae, three stones were collected at each riffle where the fish surveys were conducted and the attached algae were collected from a 5 × 5-cm area on top of the stone using a brush. The sample was filtered through a glass fiber filter (GA-100; ADVANTEC), and the concentration of chlorophyll *a* was quantified following the UNESCO method (SCOR/UNESCO, 1966). Aquatic insects were collected from three quadrats that were placed in the same riffles as used for the fish surveys using a 50 × 50-cm Surber sampler net (300-μm mesh). The samples were fixed in 99% ethanol solution and the number of aquatic insects was counted in the laboratory.

The coverage of inorganic matter on stones was also quantified as an indicator of the feeding conditions. Before collecting the aquatic insect sample from each site, the coverage of silt on stones with a diameter > 64 mm was recorded to the nearest 5%.

2.3 Data analysis

Differences in the abundances of attached algae and aquatic insects and the coverage of silt between the study periods and rivers were compared using two-way analysis of variance, followed by Sheffe's post hoc test when a significant difference was found. These analyses were performed using StatView (ver. J5.0, SAS Institute) with a significance level of $p < 0.05$.

3 Results

3.1 Main gut contents of Japanese dace

A total of 220 individuals of Japanese dace were used in the gut content analysis (Table 1). These fish ranged in size from 70.8 ± 3.7 mm to 151.3 ± 13.3 mm total length, with the sampled fish in the Koshibu River falling within the range of those that were sampled in the Toyama River. In the impacted river (the Koshibu River), the gut contents mainly

Table 1. Numbers and body sizes of sampled fish.

Sampling season	Number	Total length (mm) average (standard deviation)	
Koshibu River (impacted)			
June	28	114.2	(21.3)
September	55	102.8	(26.1)
October	109	116.8	(27.5)
Toyama River (reference)			
June	7	151.3	(13.3)
September	16	74.0	(22.4)
October	5	70.8	(3.7)

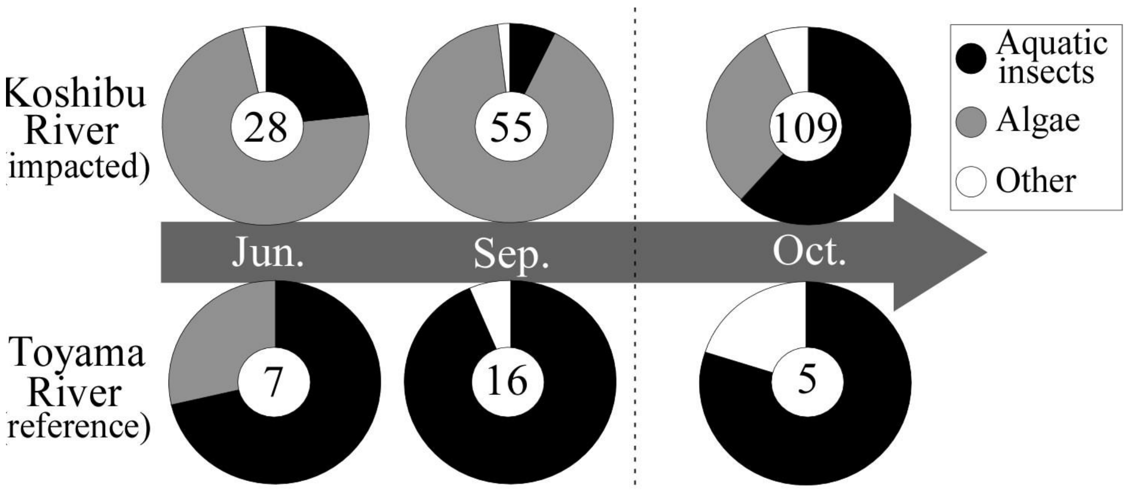

Fig. 2 Gut contents of Japanese dace (*Tribolodon hakonensis*) in the Koshibu and Toyama Rivers. Numbers in the center of the circles indicate the number of individuals sampled and the dotted line indicates the timing of sediment addition through the sediment bypass tunnel.

comprised algae before the sediment addition (Fig. 2), with similar patterns being observed in June and September 2016 (algae = 73% and 91%, aquatic insects = 23% and 7%, and others = 4% and 2%, respectively). However, after sediment addition through the sediment bypass tunnel of the Koshibu Dam, the proportion of aquatic insects increased to become dominant (61% with 109 individuals) relative to algae (31%) and others (7%), indicating a shift in prey use. By contrast, in the reference river (the Toyama River), the gut contents mainly comprised aquatic insects throughout the study period. Accordingly, the gut contents in the impacted river became similar to those in the reference river after the sediment addition.

3.2 Prey resources

The pattern of change in the chlorophyll *a* content of attached algae significantly differed between the two rivers ($p < 0.01$; Fig. 3A). In the impacted river, the chlorophyll *a* content significantly changed during the study period, increasing from June to September and then decreasing in October ($p < 0.01$), whereas in the reference river, it remained low throughout the study period ($p > 0.05$). Similarly, the pattern of change in the number of aquatic insects also significantly differed between the two rivers ($p < 0.01$; Fig. 3B), increasing before the sediment addition and then decreasing again after the sediment addition in the impacted river ($p < 0.01$). By contrast, in the reference river, the number of aquatic insects remained relatively constant although the mean number was higher in June 2016, this was not significant due to the high variance.

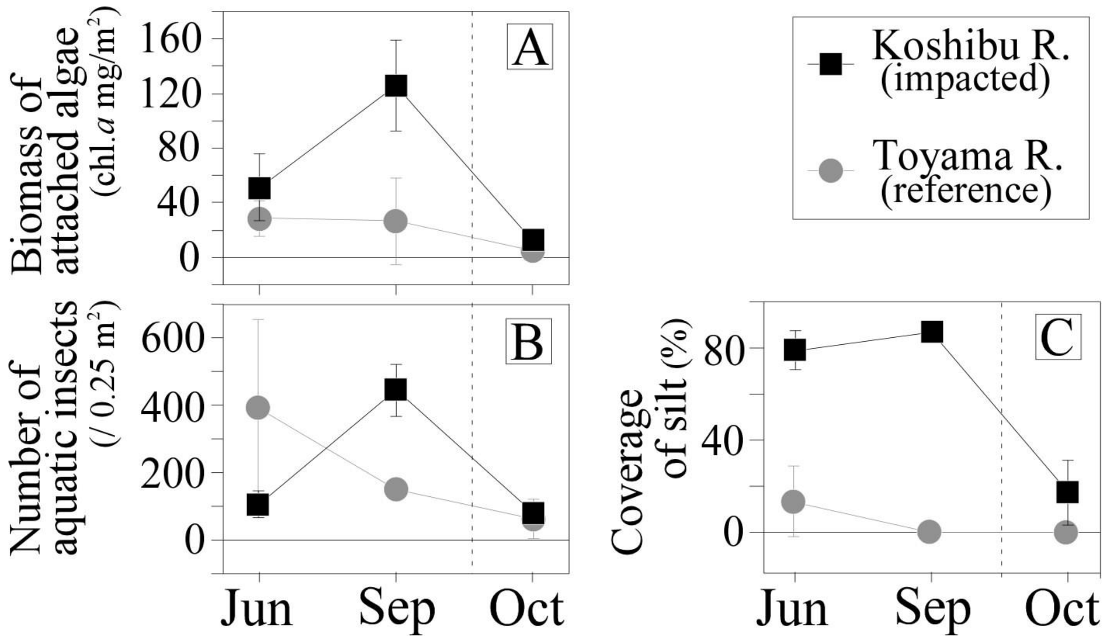

Fig. 3 Changes in the prey resources and feeding conditions in the impacted river (Koshibu River) and reference river (Toyama River). A. biomass of attached algae, B. number of aquatic insects, and C. coverage of silt. Values are means ± standard deviations. Dotted lines indicate the timing of the sediment addition.

3.3 Feeding conditions

The pattern of change in the coverage of silt on stones significantly differed between the two rivers ($p < 0.01$; Fig. 3C). In the impacted river, the coverage of silt was significantly higher in the period before sediment addition than after the addition ($p < 0.01$), whereas in the reference river, the coverage remained low throughout the study period.

4 Discussion

In this study, we found that sediment addition through the sediment bypass tunnel of the Koshibu Dam caused the main gut contents of Japanese dace to shift from algae to aquatic insects, increasing their similarity to the gut contents of fish inhabiting a reference river with no large dams. This shift was clearly caused by the sediment addition because it only occurred after the sediment addition in the Koshibu River. Japanese dace is known to be an omnivore that is biased toward eating insects (Nakamura 1969), although its food habits can differ between rivers (Komatsu 1970). Thus, the shift to preferring insects could indicate a recovery to the inherent feeding habit of this fish. Because animal material is a higher quality food than plant material (Horn 1989), this shift could be advantageous for the growth of the fish. Therefore, the diet shift caused by the sediment addition is likely to be preferable and is, thus, considered a positive effect.

The observed shift in the gut contents toward aquatic insects is likely to have been caused by a decrease in the coverage of silt rather than a change in the abundance of prey following the sediment addition. Although the biomass of algae decreased after the sediment addition, the gut contents mainly comprised algae in June when there was a comparably low algal biomass. Furthermore, the observation that algae was the main component of the diet of fish inhabiting the Koshibu River in September when the density of aquatic insects was high indicates that this shift was not caused by a change in the abundance of aquatic insects. While it is possible that a difference in body size of the sampled fish could explain such a shift, as larger Japanese dace are known to exhibit a greater bias toward eating aquatic insects (Hiro and Nakanishi 1967), even smaller fish in the Toyama River than in the Koshibu River also exhibited a bias toward eating insects. By contrast, the pattern of the dominance of algae in the gut contents changed in a similar way to the silt coverage on stones in both the impacted and reference rivers, suggesting that the observed shift was related to a decrease in silt following the sediment addition. This may have been due to a decrease in silt coverage making it easier for the Japanese dace, which are known to be visual feeders (Tsuruta et al. 2010), to search for and find aquatic insects, resulting in an improved feeding efficiency.

In conclusion, the results of this study suggest that artificial sediment addition can affect the prey use of an omnivorous fish by changing the condition of the feeding habitat. Since omnivorous fishes tend to be common (or at least not uncommon) in inland waters (Sawara 1987, Li et al. 2015), a similar positive effect can be expected by sediment addition from other dams. However, prey selection by fish is flexible and determined by many factors, such as prey availability, growth stage, prey size and density, predation risk, and individual differences (Sawara 1987, Wootton 1998, Allan and Castillo 2007). Therefore, further studies should be undertaken to determine whether this positive effect on the prey use of this omnivorous fish is a generality and to better understand the effects of sediment bypass tunnels that can release sediments under near-natural conditions.

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