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Distribution pattern of loaches (Teleostei: Cobitoidea) in the River East Tiaoxi, China

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Abstract. The distribution patterns of loaches (Teleostei: Cobitoidea) were revealed in the River East Tiaoxi in China. Eight loach species (*Cobitis sinensis*, *C. dolichorhynchus*, *C. laterimaculata*, *Misgurnus anguillicaudatus*, *Paramisgurnus dabryanus*, *Leptobotia tchangi*, *Vanmanenia pingchowensis* and *V. stenosoma*) were found in field surveys at 90 sites. A macroscale analysis of the geographical distribution showed that related species were segregated in accordance with longitudinal alterations along the river course. *M. anguillicaudatus* was widely distributed from the middle reaches to upstream of the river whereas the related species, *P. dabryanus*, was distributed only downstream. Three spined loaches, namely *C. dolichorhynchus*, *C. sinensis*, and *C. laterimaculata*, were distributed in the middle reaches, the middle to upstream reaches, and the upstream section of the river, respectively. The distribution of *V. pingchowensis* was further upper stream than that of *V. stenosoma* in the upstream section. More detailed microscale analysis revealed that *L. tchangi* and the two *Vanmanenia* species, *V. stenosoma* and *V. pingchowensis* were mostly found in the 'Riffle' (lotic) habitats, whereas the two spined loaches, *C. laterimaculata* and *C. sinensis* preferred the 'Pool' (lentic) habitats. These results demonstrated that related loach species preferred similar habitat units in the River East Tiaoxi system.

Key words: cluster analysis, longitudinal distribution, Cobitinae, Botiinae, Gastromyzoninae, habitat selection, spined loach

Introduction

Freshwater loaches belonging to the Cobitoidea are distributed broadly throughout the Eurasian continent and neighbouring islands (Nelson 2006). The adaptation of loaches to a variety of different environments has generated a diversity of species; to date, approximately 85 genera and 770 species of loaches have been reported (Nelson 2006). Some loach species, however, have become endangered due to habitat degradation (IUCN 2010).

The River East Tiaoxi is one of the largest rivers in the Lake Taihu basin which has the highest fish species density among the River Yangtze systems, China (Fu et al. 2003). The River East Tiaoxi plays a significant role relating to the aquatic biodiversity since it contains a wide variety of environmental conditions ranging from steep mountain streams to large lowland rivers. However, over the past decade, with the rapid economic and social development in this region, the corresponding degradation of aquatic environments surrounding the river has become an increasingly urgent issue (Sato et al. 2010). Nevertheless, to date, little has been reported about the exact nature of the biodiversity of freshwater fishes in the river. The natural assumption would be that the freshwater fishes in the region have been affected by such rapid environmental changes. To implement appropriate conservation measures for any species, knowledge of the natural biology of the species in question is essential (Washitani & Yahara 1996). To this end, the

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elucidation of the distribution patterns of freshwater fish provide substantial geographical and biological information as a starting basis for the formation and implementation of conservation policy (Nakajima et al. 2008).

The main purpose of the present study was to identify such distribution patterns for the loach species found in the River East Tiaoxi in order to provide as basis for the development of strategies for conservation and management of loach, and that of their wider environment.

Material and Methods

Sampling of fish and measurement of the physical environmental variables were conducted in October and November 2009 and May of 2010 covering at a total of 90 sites in the River East Tiaoxi system (Fig. 1). The investigations were conducted either by wading in shallow reaches (28 sites) or by the use of a small boat in the deeper reaches (62 sites).

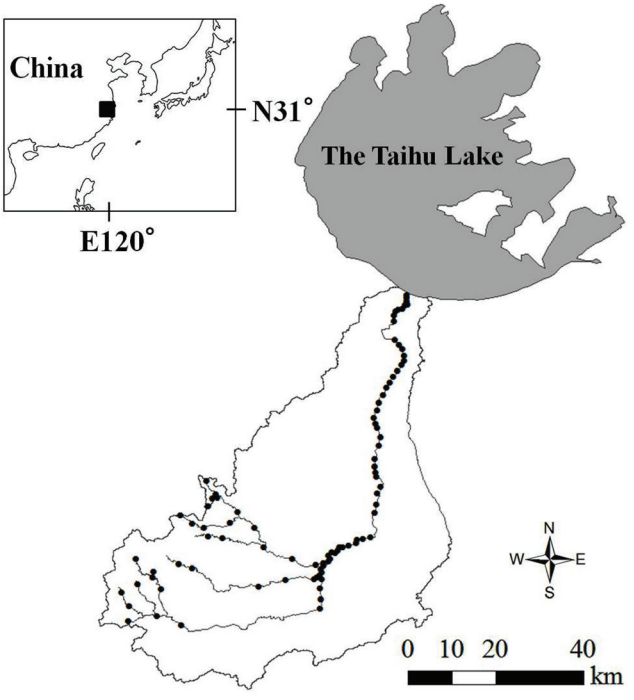

Fig. 1. *Map of the River East Tiaoxi, China, showing the 90 sampling sites represented as dots.*

In the shallow reaches, where riffle-pool structures occurred, sampling was conducted at three main habitat units (Riffle, Glide and Pool). We electrofished in each habitat unit along a 15 m stretch with a width of 2 m, using a backpack electrofisher (LR-24; Smith-Root Inc., Vancouver, Washington). As this was conducted, there were always at least two netters present to capture stunned fishes. In the deeper reaches, fishes were caught from the boat with a locally purchased electrofisher (Weibociliji; Caifu, unknown city), which has been generally used by the local fishermen around the River East Tiaoxi and the Lake Taihu. The boat was driven at a slow speed (approximately 10 m per minute) along the river shore for 50 m and fish individuals were caught within a width of 2 m.

Most captured fish were identified to the species level on site and afterwards released alive. Only uncertain individuals were anestesised by eugenol solution and fixed in formol. The identification of loach species followed Kim et al. (1999), Yue (2000), Son & He (2001), Son & Kim (2002), Nalbant (2004) and Chen & Chen (2005a, b).

Local environmental variables (current velocity, water depth, substrate size and turbidity) were also analyzed. In the present study, most of loaches were distributed from middle to upstream, where have few vegetation at riverside. Therefore, we did not evaluate vegetation availability. In shallow reaches, these environmental variables were measured at several points (approximately 10-20 points) that were randomly selected in a fish-sampling unit. Current velocity and water depth were measured at each point by using a portable current meter (VR-301, KENEK Co., Tokyo, Japan) and a metal ruler, respectively. Substrate size at each point was determined by collecting and measuring substrate at each specific point. The three local environmental variables at each point were averaged as representative values for each unit. In the deeper reaches from the mid reaches to the downstream areas of the River East Tiaoxi, there exists little longitudinal gradient (nearly zero) and correspondingly, the river had negligible water flow and a muddy bottom consisting of silt and clay. Therefore, we regarded the current velocity in such sites along the deeper reaches as zero, and substrate size as 0.001 cm based on the USDA soil classification (http://www.usda.gov/wps/portal/usda/usdahome). Turbidity was measured by a portable turbidity meter (HI93703-B; HANNA instruments Japan, Tokyo). In addition, geographical variables of altitude, gradient and distance from the Lake Taihu were measured from the sampling sites. The altitude and gradient were measured on a digital map from ASTER GDEM, a product of METI (Ministry of Economy, Trade and Industry, Japan) and NASA. The altitude was defined as the central point of each site, and the gradient was calculated for a longitudinal 1 km difference in elevation. The distance from the Lake Taihu was obtained from Google Earth (http://earth.google.com).

The data analysis revealed the distribution pattern of loach species initially at a geographical scale. A hierarchical clustering method with the Ward linkage method based on the presence/absence data of sites was applied to evaluate the similarity of appearance patterns for loach species. This analysis was conducted using statistical software R (version 2.11.1) and its optional packages, together with self-made and online-available scripts. The environmental variables of the sites were compared between 8 loach species by the Tukey method (with significant p-value set as 0.05). The distribution pattern of the loach species at a habitat unit scale was then analyzed by calculating the percentage of habitat unit utilization based on the abundance data for the respective species. The three types of habitat units (Pool, Glide and Riffle) were sampled quantitatively in the field investigations. The abundance data for each loach species therefore enabled the identification of the kinds of habitat units preferred by each loach species. The analysis excluded *Paramisgurnus dabryanus* and *Cobitis dolichorhynchus* because the two species were distributed exclusively from the middle reaches to downstream, where the river had no riffle-pool structures.

Results and Discussion

Eight loach species belonging to the Cobitidae, Botiidae and Balitoridae were found in the field survey (871 individual). Three *Cobitis* species (Cobitidae), *C. sinensis* (Fig. 2a), *C. dolichorhynchus* (Fig. 2b) and *C. laterimaculata* (Fig. 2c, a species endemic to Zhejiang Province) were recorded at two sites, three sites and eight sites, respectively. *Misgurnus anguillicaudatus* (Cobitidae, Fig. 2d) was the most common and broadly distributed loach species and it was collected at 14 sampling sites in the River East Tiaoxi system. *P. dabryanus* (Fig. 2e), on the other hand, were caught at only two sites. *Leptobotia tchangi* (Botiidae, Fig. 2f) was also uncommon in the river system, and was only collected at three sites. Two *Vanmanenia* species (Balitoridae), *V. pingchowensis* (Fig. 2g) and *V. stenosoma* (Fig. 2h) were collected at 10 and 9 sites, respectively. The two *Vanmanenia* species and *C. laterimaculata* were more common than *M. anguillicaudatus* in the upstream reaches. The environmental variables showed a wide range because sampling sites were extensively distributed from the river mouth to the upstream area. The major changes in environmental characteristics occurred from the mid reaches to the upstream in the River East Tiaoxi due to altitude changes.

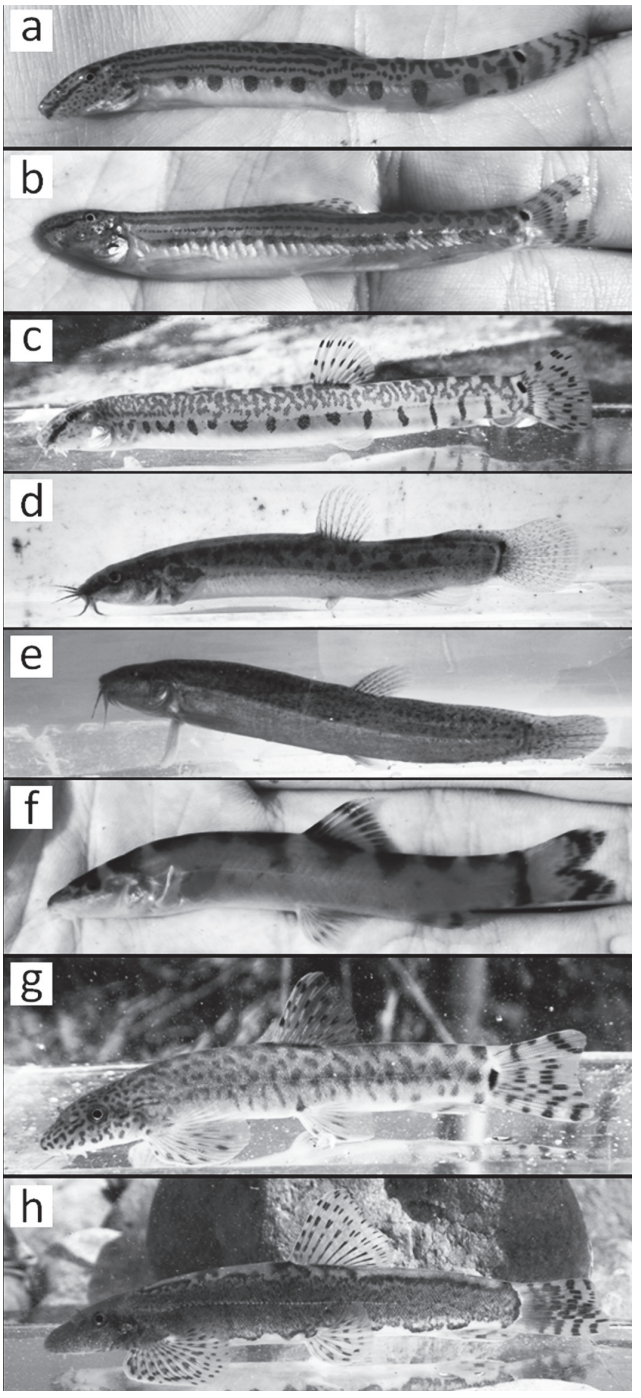

Fig. 2. *The eight loach species found in the River East Tiaoxi. a,* Cobitis sinensis*; b,* Cobitis dolichorhynchus*; c,* Cobitis laterimaculata*; d,* Misgurnus anguillicaudatus*; e,* Paramisgurnus dabryanus*; f,* Leptobotia tchangi*; g,* Vanmanenia pingchowensis*; and h,* Vanmanenia stenosoma.

Distribution pattern at the geographical scale

The geographic distribution pattern of each species was as follows. The three spined loaches, *C. dolichorhynchus*, *C. sinensis* and *C. laterimaculata*, were distributed in the middle reaches, the middle

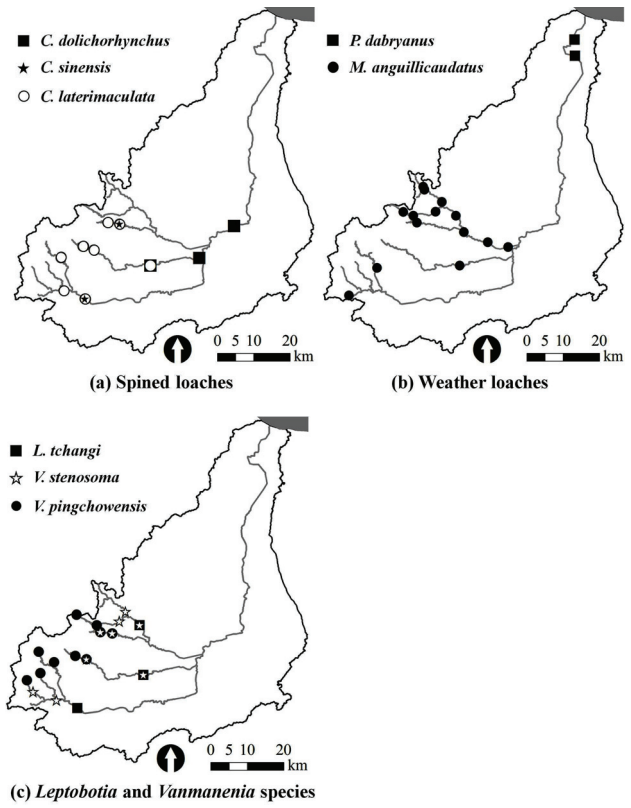

Fig. 3. *Geographic distribution patterns of the related species; (a) The spined loaches (*C. sinensis, C. dolichorhynchus *and* C. laterimaculata*), (b) The weather loaches (*M. anguillicaudatus *and* P. dabryanus*) and (c) the* Leptobotia *and* Vanmanenia *species (*L. tchangi, V. pingchowensis *and* V. stenosoma*).*

to upstream and the upstream area of the river, respectively (Fig. 3a). The distribution areas of these three, therefore, changed longitudinally with a certain degree of overlapping. *M. anguillicaudatus* was widely distributed from the middle reaches to upstream of the river (Fig. 3b) whereas the related species, *P. dabryanus*, was found in the downstream area near the Lake Taihu (Fig. 3b). The geographical distribution of two weather loaches was thus entirely distinct. The two *Vanmanenia* species were distributed in the upstream section of the river. However the distribution of *V. pingchowensis* was further upper stream than that of *V. stenosoma* (Fig. 3c). Overall, the distribution pattern of loaches indicated that the related species segregated in accordance with longitudinal alteration of the river from upstream to downstream. Nakajima et al. (2008) also reported that *Cobitis*. sp. 'yamato' complex and *Cobitis striata* (Cobitidae) segregated longitudinally in the same river systems in northern Kyushu Island, Japan. The present results are in good agreement with this report and support the view that interspecific difference in the longitudinal distribution of genuine freshwater fishes is an important factor for their co-occurrence.

Cluster analysis revealed three distinct groups represented by the downstream group (*C. dolichorhynchus* and *P. dabryanus*), the middle reaches group (*C. sinensis* and *L. tchangi*) and the upstream group (*C. laterimaculata, V. pingchowensis* and *V. stenosoma*) (Fig. 4). *M. anguillicaudatus* did not belong to any of these three groups because of its broad and allopatric distribution. We compared the environmental variables (local variables; current velocity, substratum size and turbidity, geographical variables; altitude, gradient and distance from the Lake Taihu) of the sites where each loach species was found (Fig. 5). Precise differences between *M. anguillicaudatus* and other species were not found for any of the geographical variables. However, the local variables (current velocity and substrate size) of the sampling sites where *M. anguillicaudatus* was found were significantly lower than those of several other loach species (Tukey test, $P < 0.05$). The specific distribution of *M. anguillicaudatus* depends less on geographical factors and more on the local environment of the river. Previous studies reported that *Misgurnus* species inhabits a wide range of habitats, lakes, ponds, rivers, streams and ditches with slow current and mud bottom (Saitoh 1989, Kottelat & Freyhof 2007 and Kano et al. 2010). *M. anguillicaudatus*, it seems, can inhabit most areas which exhibit lentic conditions and muddy substrate regardless of other geographical changes in the nature of the river.

Distribution pattern at habitat scale

More detailed habitat unit scale analysis identified the

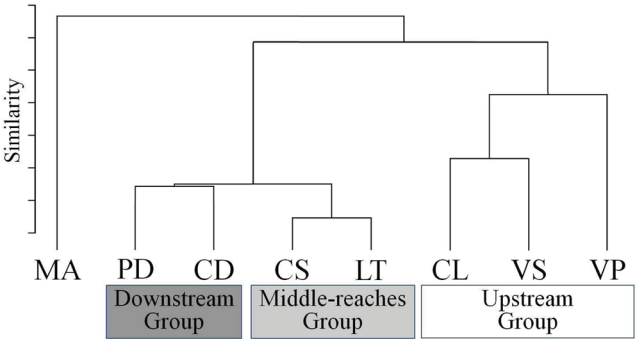

Fig. 4. *The similarity of appearance patterns for the eight loach species by using the cluster analysis based on the presence/absence data of sites. CA,* C. sinensis*; CD,* C. dolichorhynchus*; CL,* C. laterimaculata*; MA,* M. anguillicaudatus*; PD,* P. dabryanus*; LT,* L. tchangi*; VP,* V. pingchowensis*; and VS,* V. stenosoma*.*

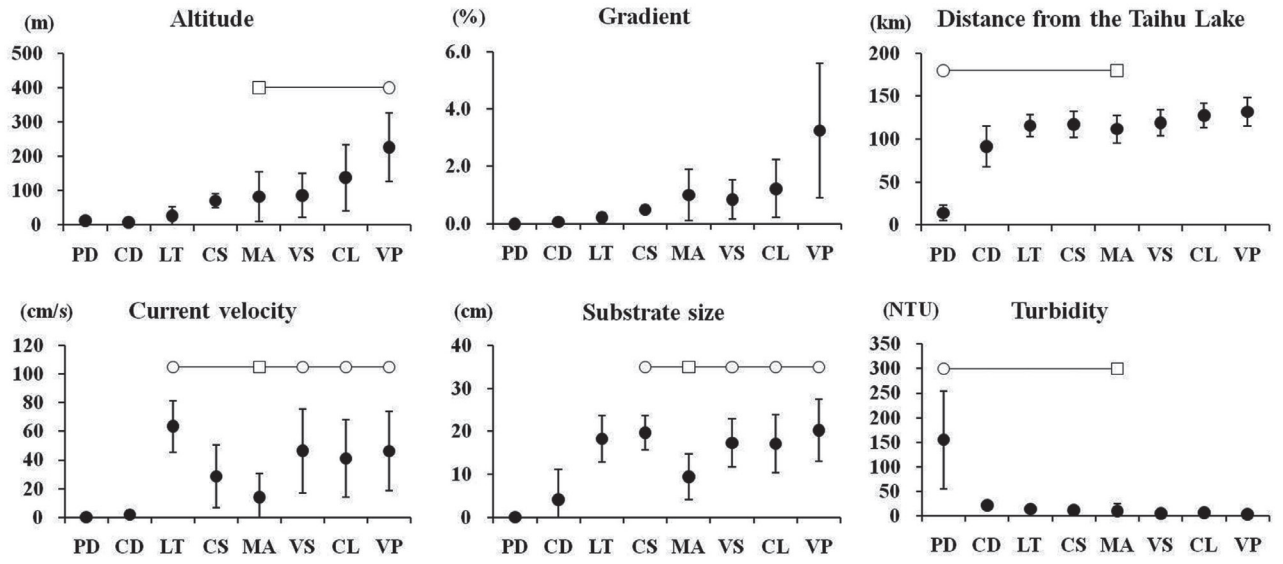

Fig. 5. *Comparison of six environmental variables (the local variables 'current velocity' and 'substrate size', and the geographical variables, 'altitude', 'gradient', 'distance from the Taihu Lake' and 'Turbidity') at the sites in which species were recorded. Bars represent standard deviation. Open circles indicate the significant differences between open squares (*M. anguillicaudatus*) analysed using the Tukey's test ($p < 0.05$). Species names are same as those in Fig. 4.*

kinds of habitat units preferred by each loach species (Fig. 6). The physical characteristics of three habitat units are shown in Fig. 7. Fig. 6 shows that *L. tchangi* and the two *Vanmanenia* species; *V. stenosoma* and *V. pingchowensis* preferred the 'Riffle' and 'Glide' habitats (lotic areas) than 'Pool' habitat (lentic area). There have been few researches on natural ecologies of *Leptobotia* and *Vanmanenia* species. Huang & Wu (2010) reported that *Vanmanenia xinyiensis* lives in mountain streams with fast current. *V. stenosoma* and *V. pingchowensis* had same habitat preferences as *V. xinyiensis*. Previous study reported that *Leptobotia elongate* lives in swift-flowing of the upper and middle streams of rivers or mountain streams (Liang et al. 2009). *L. tchangi* also preferred fast current but inhabited just middle reaches. *Cobitis* species have adapted to a wide variety of habitats including lakes, rivers, mountain streams and irrigation channels with still to fast-flowing water (Robotham 1978, Kottelat & Freyhof 2007, Nakajima et al. 2008 and Kawanishi et al. 2010). The two spined loaches; *C. laterimaculata* and *C. sinensis*, showed a preference for the 'Pool' and 'Glide' habitats (lentic areas) from middle to

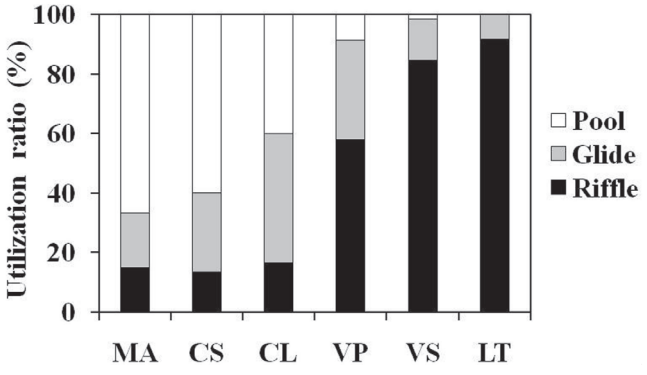

Fig. 6. *The percentage of habitat units utilized based on the abundance data in each respective species. Species names are same as those in Fig. 4.*

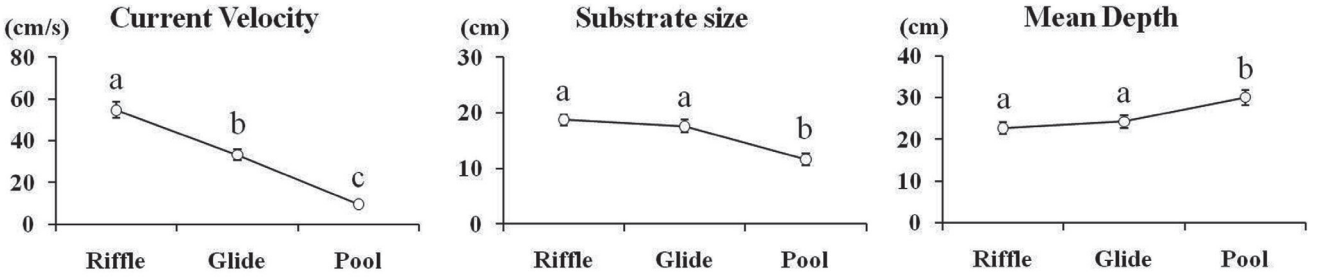

Fig. 7. *Comparison of environmental variables between habitat units. In each graph, bars represent standard error. The same letter above bars shows that values were not statistically different (Tukey test; $P < 0.05$).*

upstream reaches. As expected, *M. anguillicaudatus* were mainly distributed in the 'Pool' habitats with mud bottom. These results demonstrate that related loach species preferred similar habitat units in the River East Tiaoxi system.

In conclusion, the present study identified the distribution patterns of the loach species found in the River East Tiaoxi. The geographical scale analysis showed that the related species segregated in accordance with longitudinal alteration of the river course. The habitat unit scale analysis revealed that the related species showed a preference for similar habitat units. We assume that the related loach species that utilize the similar microhabitat can coexist in same river system by dividing the area they inhabit longitudinally. Longitudinal change of distribution pattern in related species is one of the important mechanisms for facilitating the coexistence of similar species.

In addition, the information we obtained should be helpful for measurement and conservation of the loach species in the River East Tiaoxi. An example of a practical consideration would be that *L. tchangi* was distributed in middle reaches and preferring 'Riffle' habitat units. The habitat units, especially in the middle reaches in the River East Tiaoxi have been altered due to the continuing rapid construction of river-crossing structures such as weirs. In fact, one 'Riffle' habitat unit where *L. tchangi* had previously been observed in October of 2009 was lost due to the construction of a weir in early 2010. Thus no *L. tchangi* were re-caught in proximity to the sampling sites in May 2010. Detailed assessment and further monitoring are essential and urgent for the conservation of loach in the River East Tiaoxi, and such measures should lead to a biodiversity conservation contribution to the whole around.

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