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Habitat Use of Two Benthic Fishes, *Crossostoma lacustre* and *Rhinogobius candidianus*, in the Hapen Creek of Northern Taiwan

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ABSTRACT: Habitat use was investigated for two common endemic and benthic fishes, *Crossostoma lacustre* and *Rhinogobius candidianus*, in the Hapen Creek of northern Taiwan from August 1996 to December 1998. *C. lacustre* and *R. candidianus* overlapped in mesohabitat use; both fish species preferred riffles to pools. Further analyses based on stepwise multiple regression showed that fish density was significantly correlated with water depth, small boulder, and finer substrate for *C. lacustre*, but correlated with water depth, stream width, large boulder, and cobble for *R. candidianus*. The separation in the microhabitat use might have alleviated the pressure for interspecific competitions despite of their overlapping in the mesohabitat scale. Parallelly, the result suggests that the diverse substratum composition may have accounted for the co-exsitence of these two benthic fishes. It would also provide valuable information for habitat management and ecological engineering of mountain creeks in Taiwan.

KEY WORD: ***Crossostoma lacustre*, *Rhinogobius candidianus*, Riffle, Pool, Taiwan.**

INTRODUCTION

Hydrological and geomorphological conditions of streams are highly variable and dynamic, and provide diverse habitats for fishes and other aquatic organisms. Among the environmental features, physical habitat structure represents an important component to determine the abundance, distribution, and species composition of stream fishes (Gorman and Karr, 1978). The relationships between physical habitat variables and fish distributions have been investigated in many temperate streams (e.g. Taylor, 1996; Gray and Stauffer, 1999, Vadas and Orth, 2000; Sone *et al*., 2001; Heggenes, 2002) and tropical lotic waters (Gorman and Karr, 1978; Moyle and Senanayake, 1984; Dudgeon, 1987; Wikramanayake and Moyle, 1989; Martin-Smith, 1998).

The relationship is of particular interests because it may, in one hand, help to explain how sympatric species may co-exist (Schlosser and Toth, 1984; Heggenes and Saltveit, 1990; Inoue and Nakano, 2001); and on the other hand, to provide fundamental information for habitat management (Rabeni and Sowa, 1996). In Taiwan, a small mountainous island with short and swift flowing headwaters have been explored for the spatial distribution and abundance of freshwater fishes(Chang, 1989; Huang, 1998; Lee *et al*., 1998; Han *et al.*, 2000). However, specific examinations on the habitat use of stream benthic fishes are few (Yu and Lee, 2002).

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Crossostoma lacustre (Balitoridae) and *Rhinogobius candidianus* (Gobiidae) are two endemic and benthic fish species that are common in many mountain streams in northern and central Taiwan (Wang and Shao, 1997; Chang *et al.*, 1999; Chen and Fang, 1999). The objectives of this study were to: (1) understand the habitat use of *C. lacustre*. and *R. candidianus* in Hapen Creek, a protected stream in northern Taiwan; (2) examine whether segregation occurred between these two species along habitat dimension.

MATERIALS AND METHODS

Study area and sampling sites

This study was conducted in Hapen Creek, a headwater tributary of the Tanshui River at elevations of 500 m to 1,200 m. It was a natural, well-protected mountain creek in the Fushan Experimental Forest in the northern Taiwan (Fig. 1). Torrential rainfalls brought by typhoons that cause rapid increase in water flows are the most important factor affecting hydrological characteristics of the creek (Hsia and Hwong, 1999). Gauging station records of Fushan meteorological station showed that the mean annual precipitation in the Hapen Creek watershed was 4,671 mm from 1996 to 1998, and the mean annual discharge of Hapen Creek was 0.352 m^3s^{-1}, with mean monthly discharge ranging between 0.012 m^3s^{-1} and 0.063 m^3s^{-1} from 1993 to 2000. The monthly mean air temperature ranged from 11.5 ℃ to 23.7 ℃. The riparian zone of Hapen Creek was covered primarily with natural broadleaf forests. The fish fauna was *Varicorhinus barbatulus*, *Candidia barbatus*, *C. lacustre*, *R. candidianus*, *Cobitis sinensis*, and *Acrossocheilus paradoxus* (Chang *et al*., 1998).

Three study sites, S1, S2, and S3 (from upstream to downstream), were selected, each with four habitat units (two pools and two riffles; defined as mesohabitat), as replicates. A riffle was a section of the stream where water surface has visible standing or breaking anti-waves, whereas a pool was the section with smooth water surface and no such breaking anti-waves (Gelwick, 1990). The distances of S1, S2, and S3 to the confluence of the Hapen Creek to the main branch of the Tanshyui River were 4.2 km, 1.6 km and 0.7 km, respectively. The average gradient of the study area is 17.5 m/km (Chang *et al.*, 1998)

Fish sampling and fish densities

Fish sampling was conducted at each study site every two-month from August 1996 to December 1998. A total of 88 samples were collected from each of the riffles and the pools. At each of the two habitat units, fishes were sampled by electrofishing for a 15-minute period from downstream to upstream. A battery-powered, backpack-mounted electrofisher (150-300 V, 1 A pulsed DC) was used. Two field assistants helped collect stunned fishes with dip nets. Fishes collected were identified to species and their total lengths (TL) were measured in the field, and released alive at the site. Fish density was calculated by dividing the number of fishes by sampled area of each habitat unit (stream length x mean stream width).

Hydrological variables and microhabitat conditions

Hydrological variables and habitat conditions were measured at each of the riffles and pools with methods described by Tsao (1995) immediately after the fish sampling. The parameters, i.e. microhabitat conditions, measured were stream width, water depth, current velocity, dominant substrate type, instream cover, and canopy.

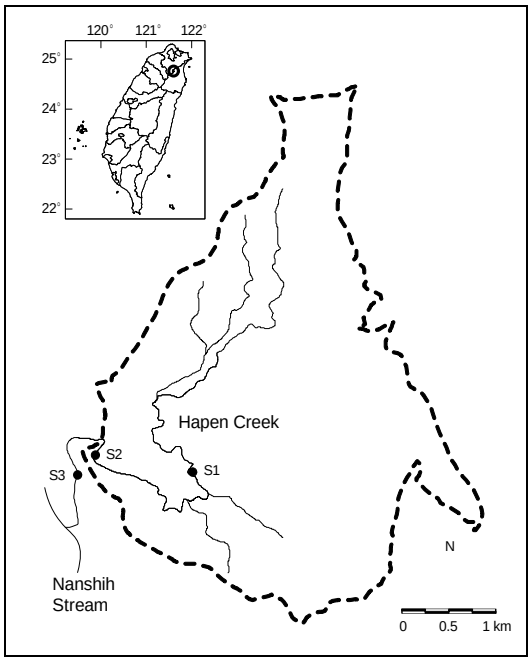

Fig. 1. Map showing sites (S1-S3) of fish sampling and data collections of hydrological and environmental variables at Hapen Creek of the northern Taiwan. The dotted line denotes the boundary of Fushan Experimental Forest.

In the field, three permanent transects perpendicular to current flow were delineated along each habitat unit. Stream width was measured by the length of transect above water surface. Water depth, velocity, and substrata were measured at 1 m intervals along transects. At each measurement point, depth was measured with a metric stick (in cm), and dominant substrate type was classified into five ranks based on the diameter ranges: sand and gravel (<16 mm), pebble (16-64 mm), cobble (64-256 mm), small boulder (256-512 mm), and large boulder (>512 mm) (Tsao, 1995). Current velocity was measured at 60% of depth from water surface using a digital current meter (Swoffer, Model 2100). The mean width, depth, and velocity of each habitat unit were used to calculated water flow. Four types of instream cover were recorded (open water, visual isolation, velocity shelter, and combination of visual isolation and velocity shelter), each as percentage of surface area of the habitat unit. Visual isolation is caused by instream and offstream overheads such as undercut banks, floating vegetation, and open log jams. Velocity shelter is derived from instream objects such as large rocks, bedrock ledges, and partially buried logs (Tsao, 1995). Canopy was measured with a spherical densiometer (Model C, Forest Densiometer, Barthesville, OK, U.S.A.) upon water surface. For each measurement, average reading was calculated from the four readings facing north, south, east, and west.

Data analysis

Unpaired *t*-tests were used to compare fish densities, stream width, water depth, current velocity, substrate type, instream cover, and canopy between riffles and pools. Stepwise multiple regression analyses were used to determine which physical habitat characteristics were associated with fish densities. Pearson's correlation analyses were used to examine the correlations between the densities of these two fish species. Prior to both regression and correlation analyses, square root transformation was used to standardize variances and to improve normality of the data (Sokal and Rohlf, 1995).

RESULTS

General hydrological variables and habitat conditions

Hapen creek is a small mountain creek with highly fluctuated hydrological variables and habitat conditions. During the study period, the water flows varied between 0 m^3/sec and 4.85 m^3/sec with an average of 0.75 m^3/sec, and current velocities averaged at 0.47 m/sec with a range between 0 m/sec and 1.32 m/sec. In summer some riffles lost surface water, and the water flowed subterraneously beneath gravel bottom. The mean water depth was 0.23 m with a range of 0.02 m to 0.61 m, and the stream width averaged at 6.1 m with the range of 1.7 m to 10.5 m.

Differences in habitat conditions between riffles and pools

Hydrological and environmental conditions of Hapen Creek showed obvious differences between pools and riffles (Table 1). The bottom substrates of both pools and riffles were predominantly composed of pebble, cobble, and large boulder, but the pools had a higher percent composition of pebble but lower composition of cobble, small boulder and large boulder as compared with the riffles. Water depths at the pools were significantly deeper than those at the riffles, whereas current velocities in the riffles were significantly faster than those in the pools. There was no significant difference in stream width between pools and riffles for this mountain creek. The creek was mainly open water with a few instream covers, but canopy was over 80% on the pools and 60% on the riffles.

Table 1. Comparisons of hydrological and environmental variables (mean ± SD) between pools and riffles of Hapen Creek.

Variables	Pools	Riffles	*t*-values
Stream width (m)	6.20 ± 1.81 (N = 88)	5.91 ± 1.59 (N =88)	1.1
Water depth (m)	0.31 ± 0.11 (N = 88)	0.19 ± 0.08 (N =88)	8.1^{***}
Current velocity (m/sec)	0.32 ± 0.23 (N = 88)	0.60 ± 0.27 (N =88)	-7.4^{***}
Substrate (%)			
Sand and gravel	9.2 ± 16.4	1.8 ± 5.3	4.0^{***}
Pebble	46.6 ± 22.6	32.3 ± 25.5	4.0^{***}
Cobble	17.7 ± 14.5	30.8 ± 27.4	-4.0^{***}
Small boulder	8.0 ± 9.1	12.5 ± 12.4	-2.7^{**}
Large boulder	18.5 ± 18.4	22.6 ± 25.1	-1.2
Instream cover (%)			
Open water	84.6 ± 19.2	75.6 ± 24.5	2.7^{**}
Visiual isolation	2.9 ± 5.5	1.4 ± 4.0	2.1^{*}
Velocity shelter	5.3 ± 7.8	6.9 ± 9.3	-1.3
Combination of visiual isolation and velocity shelter	7.3 ± 15.6	16.1 ± 21.3	-3.1^{**}
Canopy (%)	85.1 ± 10.7	64.1 ± 21.8	8.1^{***}

***Significant difference between pools and riffles, $p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$.

Fish densities

During the study period, a total of 866 fishes was collected for *C. lacustre*: 706 from riffles with the densities of 4.6 ± 5.3 fish/100m^2, and 160 from pools with 1.3 ± 2.5 fish/100m^2. There was significant difference in the densities between the riffles and the pools

(t = 5.3, p < 0.001). For *R. candidianus* 790 fishes were collected: 669 from riffles with the densities of 4.5 ± 5.7 fish/100m^2, and 121 from pools with 1.3 ± 2.0 fish/100m^2. Mean densities of *R. candidianus* were significantly different between riffles and pools (t = 4.9, p < 0.001). By putting the above results together, it suggests that these two fishes had a special preference for riffles than for pools. Moreover, the densities of these two fish species were significantly positively correlated in either riffles or pools (Fig. 2).

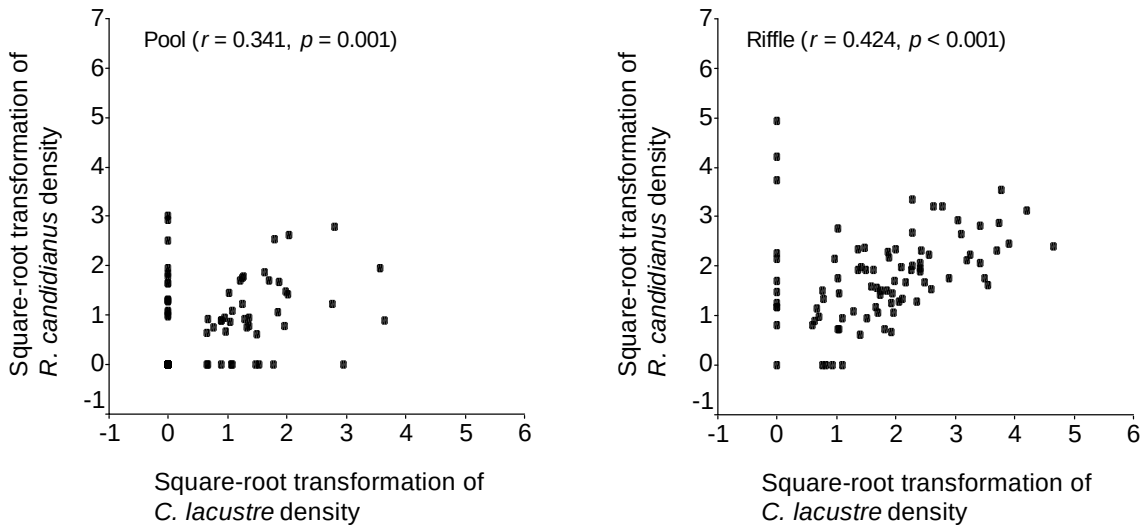

Fig. 2. Graphs showing relationships between densities (fish/100m^2) of *C. lacustre* and *R. candidianus* in pools and riffles. (N = 88)

Relationships between fish density and hydrological and habitat variables

The results of stepwise multiple regression analyses showed that fish densities of *C. lacustre* (Fc) were significantly and negatively related with water depth (D) and sand-gravel (SG), and positively related with small boulder (SB). The relationships are expressed by the following equation:

$$Fc = 2.775 - 3.843\ D + 0.187\ SB - 0.109\ SG$$
$$R^2 = 0.296,\ df = 172$$

The R^2-value suggested that 29.6% of variance of the fish densities can be explained by the one hydrological factor, water depth, and two habitat factors, small boulder and sand-gravel. Water depth was accountable for 12.4% and the sand-gravel and small boulder were 17.2% (Table 2). Thus, *C. lacustre* preferred shallow water in riffles with small boulders and avoided sand-gravels.

For *R. candidianus*, the densities (Fr) showed significantly negative relationships with water depth and stream width (W), but positive to large boulder (LB) and cobble (C). The relationships are expressed by the following equation:

$$Fr = 5.258 - 4.817\ D - 0.873\ W + 0.076\ LB + 0.059\ C$$
$$R^2 = 0.444,\ df = 171$$

The R^2 value suggested that 44.4% of the variance of fish densities can be explained by the four hydrological and environmental conditions, of which water depth and stream width were accountable for 41.0%, and large boulder and cobble for 3.3% of the variance (Table 2). Thus, *R. candidianus* preferred small stream and shallow water in riffles with medium- and large-sized substrate (i.e., cobble and large boulder).

Table 2. Model summary of stepwise multiple regressions of densities of *C. lacustre* and *R. candidianus* with habitat variables.

Variables	R^2	Regression coefficients	Standard errors	F
C. lacustre				
(Total R^2 = 0.296, N = 176)				
Depth	0.124	-3.843	0.658	24.60^{***}
Small boulder	0.144	0.187	0.042	34.04^{***}
Sand and gravel	0.028	-0.109	0.041	6.95^{**}
R. candidianus				
(Total R^2 = 0.444, N = 176)				
Depth	0.356	-4.817	0.685	96.26^{***}
Width	0.054	-0.873	0.203	15.86^{***}
Large boulder	0.020	0.076	0.025	6.11^{*}
Cobble	0.013	0.059	0.029	4.15^{*}

***Significant difference level, $p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$.

DISCUSSION

Both *C. lacustre* and *R. candidianus* preferred riffles with shallow waters, and their mesohabitat uses overlapped. However, differences in their microhabitat utilization on substrate size had occurred. *C. lacustre* preferred small boulders and avoided fine substrates. By constrast, *R. candidianus* perferred large boulders and cobbles. The separation in the microhabitat use might have alleviated the pressure for interspecific competitions despite of their overlapping in the mesohabitat scale.

C. lacustre is an omivorous feeder which feeds mainly on benthic algae and aquatic insects (Huang, 2002). In contrast, *R. candidianus* mainly feeds on aquatic insects and macroinvertebrates (such as freshwater crabs) hidden in the underwater crevice (Huang, 2002). In general, invertebrates occurred more frequently in stony riffles than in pools (Allan, 1995). In addition, macroinvertebrate faunal richness, biomass, and abundance are higher for pebbles and cobbles than boulders (Giller and Malmqvist, 1998). *R. candidianus* preferred cobbles and large boulders than other types of substrate and depended on the macroinvertebrates more than *C. lacustre* did. The macroinvertebrate-substrate relationship thus shows a consistency between its microhabitat use and trophic habit.

Dudgeon (1987) has presented data indicating that homalopterids most inhabited in midstream habitat, but gobies regularly occurred at bankside or intermediate zone habitat. Pools and stream margins generally have finer substrates than riffles and midstream (Allan, 1995). In Hapen Creek, sand and gravel are commonly distributed along bankside. Although we did not examine the inhabiting positions of these two fishes across the creek, *C. lacustre*, a homalopterid, was found avoiding sand and gravel in the field works.

Dudgeon (1987) also suggested that the differences of microhabiat utilization between homalopterids and gobies would result from morphological fitness rather than competiton determines segregation on habitat dimension. The suggestion may be an explanation to the segregations of microhabitat use by *C. lacustre* and *R. candidianus* in Hapen Creek.

At the microhabitat scale, stepwise multiple regression models revealed that the substrate composition was an important variable for habitat use of *C. lacustre* and *R. candidianus*. Therefore, it suggests that the diverse substratum composition may have accounted for the co-exsitence of these two benthic fishes. The result would also provide valuable information for habitat management and ecological engineering of mountain creeks in Taiwan.

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台灣北部哈盆溪兩種底棲魚類－台灣纓口鰍（*Crossostoma lacustre*）與明潭吻鰕虎（*Rhinogobius candidianus*）之棲地利用

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摘　　要

自 1996 年 8 月至 1998 年 12 月於台灣北部的哈盆溪流域進行台灣纓口鰍 (*Crossostoma lacustre*) 及明潭吻鰕虎 (*Rhinogobius candidianus*) 兩種底棲性魚類棲地利用的研究。結果顯示台灣纓口鰍與明潭吻鰕虎在中型棲地 (mesohabitat) 尺度的利用上有重疊現象，而且都比較偏好水淺的急流 (riffle)。經進一步以逐步複迴歸分析法 (stepwise multiple regression analysis) 分析微棲地 (microhabitat) 的利用，發現台灣纓口鰍的魚群密度與水深、小巨石 (small boulder)、細沙與小礫石 (sand and gravel) 有顯著的關係；而明潭吻鰕虎則與水深、溪寬、大巨石 (large boulder)、卵石 (cobble) 有顯著相關。雖然台灣纓口鰍與明潭吻鰕虎在中型棲地的利用上有重疊，但是微棲地利用上的區隔可能降低種間競爭的壓力。根據本研究結果，維持底石 (substrate) 的多樣化應有利於這兩底棲魚種的共存，同時對於台灣溪流在棲地經營與生態工法的施行上，也能提供具有價值的相關資訊。

關鍵詞：台灣纓口鰍、明潭吻鰕虎、急流、潭區、台灣。

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