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Environmental biology of an endemic cyprinid, *Varicorhinus alticorpus*, in a subtropical mountain stream of Taiwan

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Synopsis

An endemic freshwater fish, *Varicorhinus alticorpus*, was studied from 1990 to 1993 in a fast flowing mountain stream in southern Taiwan (22°30′N, 120°30′E). The analysis of environmental conditions suggested that the fish could tolerate water temperatures between 19–24°C, a pH of 8.0–8.8, and flow velocity from 20–100 cm sec^{-1}. The fish occupied riffles and pools. They foraged and schooled during daytime and aggregated in crevices between rocks at night. Most juveniles stayed at the shallow sandy-pebble flat by the pool where flow was slow. The species feed primarily on the periphyton growing on the rocks, and leave unique scars after grazing. One peak of juvenile recruitment was observed right after the rainy season, suggesting that reproduction of the fish has adapted to the climate. The change of abundance of adults along the habitats (at 150 to 800 m altitude) also indicated that the fish might migrate to low altitudes for spawning and disperse back to higher altitudes for exploiting new resources. The environmental biology of this fish shows an example of a cyprinid adapted to habitats in a subtropical mountain stream.

Introduction

Varicorhinus alticorpus (Cyprinidae), an endemic fish found in mountain streams of Taiwan, was first described by Oshima (1920). It used to be an important protein source for aboriginal residents in the old days. However, over the past decades, heavy fishing, illegal use of poison, and fragmentation of rivers by dams along the habitat of this fish have driven it to the edge of extinction. It has officially been listed as an endangered species in Taiwan since 1989 following a sharp decline in numbers.

Members of the genus *Varicorhinus* are widely distributed along the east and southeast area of the Asian continent (Wu 1977), as well as in Africa (Krysanov & Golubtsov 1996, Reig et al. 1998). *V. alticorpus*, however, was reported to occur only in several streams on the southeastern, and in one stream on the western part of Taiwan (22°30′N, 120°30′E) (Lin 1994). Despite being an endangered species, *V. alticorpus* was little studied. A study program of *V. alticorpus* was initiated with the aim to understand the habitat conditions and utilization, feeding behavior, and reproduction of the fish. Here we present the results of a two-year study, and describe the unique feeding behavior of this endemic species.

Materials and methods

Study sites

On the western side of Taiwan, Kaoping River and its upstream tributaries form the major water system where *V. alticorpus* occurs. The stream is only 171 km long, but descends from a more than 3000 m high mountain area to the sea. In a two-year survey starting in 1991, 32 stations along the watershed of Kaoping Stream were investigated for the occurrence of the fish. We selected eight stations at altitudes ranging from 800 to 150 m for long-term monitoring (Figure 1). Stations were chosen based on the occurrence of the fish, the variety of the habitats, and their accessibility. Samplings and observations were performed monthly from July 1992 to June 1993.

Sampling methods

Visual censuses by skin and scuba diving were carried out to observe the abundance and behavior of the fish (Fang et al. 1993) during the post-rainy season

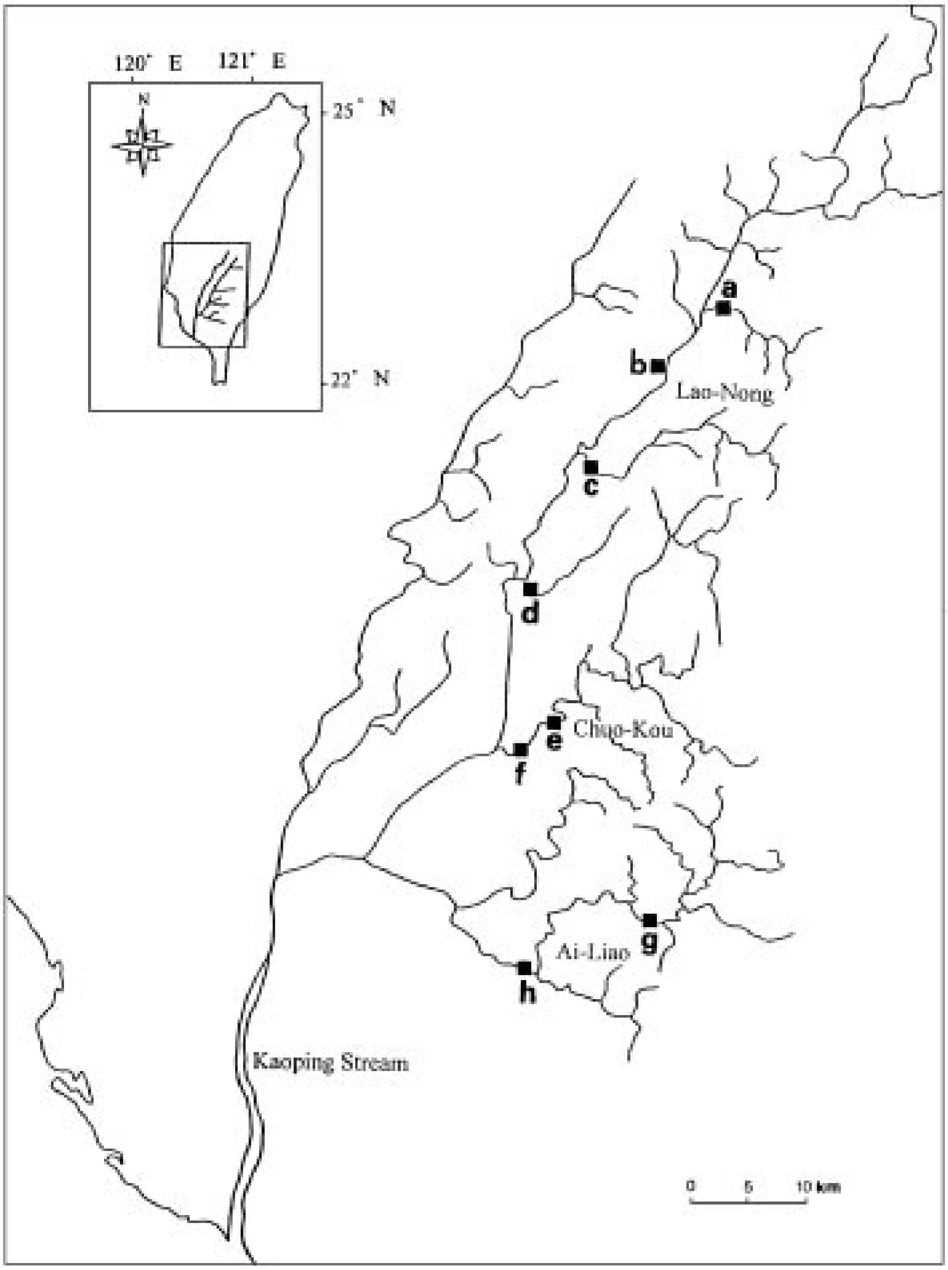

Figure 1. The locality and the eight study stations in the upper stretches of Kaoping Stream in Taiwan. Station a to d descend from the altitude of 800 to 200 m, e to f from 300 to 150 m, and g to h from 450 to 200 m.

(October to the following April). The water was clear and flowing calmly. During each survey, three divers moved upstream and counted the number of fish as suggested by Greenberg (1988) and Heggenes et al. (1990). Fish were classified into 5 size classes: 1–3 cm, 3–5 cm, 5–10 cm, 10–20 cm and 20+ cm total length by visual estimation. During the rainy season (May to September), cast net (4.5 m in diameter, mesh size 3 cm), gill net (mesh size 3 cm), and electrofisher were used to collect fish. High turbidity and violent water flow made direct observations impossible.

Environmental conditions

Environmental conditions were recorded during each survey. Stream width was measured perpendicular to the flow direction at pool area, riffle and run; and depth was averaged from the measurements along a transect at 1/3, 1/2 and 2/3 distance from the bank. Bottom substrate and the size of stones at pools, runs and riffles were classified according to Wentworth's scales (Bain et al. 1985). Hydrological conditions such as temperature, pH, dissolved oxygen, conductivity and turbidity were measured using ABB Kent-Taylor multiple probes to which a multi-functional chemistry and water quality monitor (Solomat 520C) was connected. Flow velocity was determined using a digital flowmeter (General Oceanic, model 2030R). Chlorophyll *a* was used as a parameter of the abundance of periphyton in this study. Samples were scraped from substrate and analyzed according to the method of Jeffery & Humphrey (1975) using a spectrophotometer (Hitachi, model U-3210).

Habitat utilization

To examine the habitat utilization of the fish, observations were made between 11:00 and 15:00 h when the stream was well illuminated, and underwater visibility was > 5 m. Occupancy of different habitats by different size classes of fish was recorded with the help of an underwater video camera. Night diving was conducted to observe the nocturnal behavior of the fish.

Feeding

Feeding behavior was observed during the habitat utilization survey. Since the catch and sacrifice of this species is prohibited by law, the stomach contents of the fish could only be studied by investigating the occasional by-catches of the aboriginal people. A total of eight fish was examined. In order to analyze the food items, one gram of stomach contents was suspended thoroughly in 500 ml distilled water. Then, one milliliter of suspension was taken out for examination under a light microscope ($\times 400$). Relative abundance was ranked on the basis of the occurrence of the specimens in the suspension.

Reproduction

Since *V. alticorpus* is an endangered species, the traditional analysis of gonadosomatic index was not applied to study the reproduction of the species. Instead, the seasonal presence and absence of juveniles and their abundance were recorded as an indirect assessment of the reproductive season (Fang et al. 1993, Wang et al. 1995).

Results

Environmental conditions

Riffle, pool and run are the three major habitats in the high mountain streams of Taiwan. Table 1 gives the general environmental conditions at the sites where *V. alticorpus* were observed. The fish tended to stay in areas with clear, slightly alkaline water with high levels of dissolved oxygen, a depth greater than 0.5 m and moderate to fast flow.

The chlorophyll *a* concentration of periphyton in the various habitats fluctuated throughout the year, ranging from 0.7 to 4.3 μg cm^{-2}. The highest value was found at riffles, while pool and run areas exhibited about the same concentration of chlorophyll *a* and fluctuated similarly from month to month. There was no significant

Table 1. Environmental conditions at the sampling sites where *V. alticorpus* were observed.

Environmental parameters	
Temperature	19–24°C
pH	8.0–8.8
Dissolved oxygen	$\geqq 60\%$
Conductivity	254–601 μS
Turbidity	$\leqq 50$ NTU
Stream width	3 to 21 m
Stream depth	0.5 to 6.4 m
Chl. *a*	1.5–4.5 μg cm^{-2}
Flow	20–100 cm sec^{-1}

difference (Mann–Whitney test, $p > 0.05$) in chlorophyll *a* concentrations between rainy and post-rainy season. However, the value during winter-spring time (post-rainy) was somewhat higher.

Monthly water flow at riffles was between 50 and 70 cm s^{-1} from January to June, then increased to more than 100 cm s^{-1} in July and September. Flows in pools and runs were slower, at about 20 cm s^{-1} from January to June but increased to more than 50 cm s^{-1} during the rainy season.

Bottom substrates at three different habitats were recorded and the sizes classified according to Wentworth's scale (Bain et al. 1985). More than 50% of the substratum consisted of R3-size particles (0.004–0.06 mm in diameter), whereas more than 60% of the substrates at riffles ranged from R9 to R11 (128.1–512.10 mm in diameter). The bottom of pools had a variety of substrates ranging from R3 to R9, R11 and 15–23% was bedrock (R12). Pool areas were the only habitats where bedrock was found.

Habitat utilization

The result of the initial survey at 32 stations in Kaoping Stream showed that *V. alticorpus* inhabited the waters between altitudes of 150 and 800 m. During the rainy season, most adult fish were caught in the upper stream stations (Figure 2). However, few or no fish were observed at upper stream stations during the post-rainy season, while increased numbers of fish were present in midstream stations (Figure 3). This suggests an uneven annual distribution of fish at different altitudes. Observations in May and June of 1993 were

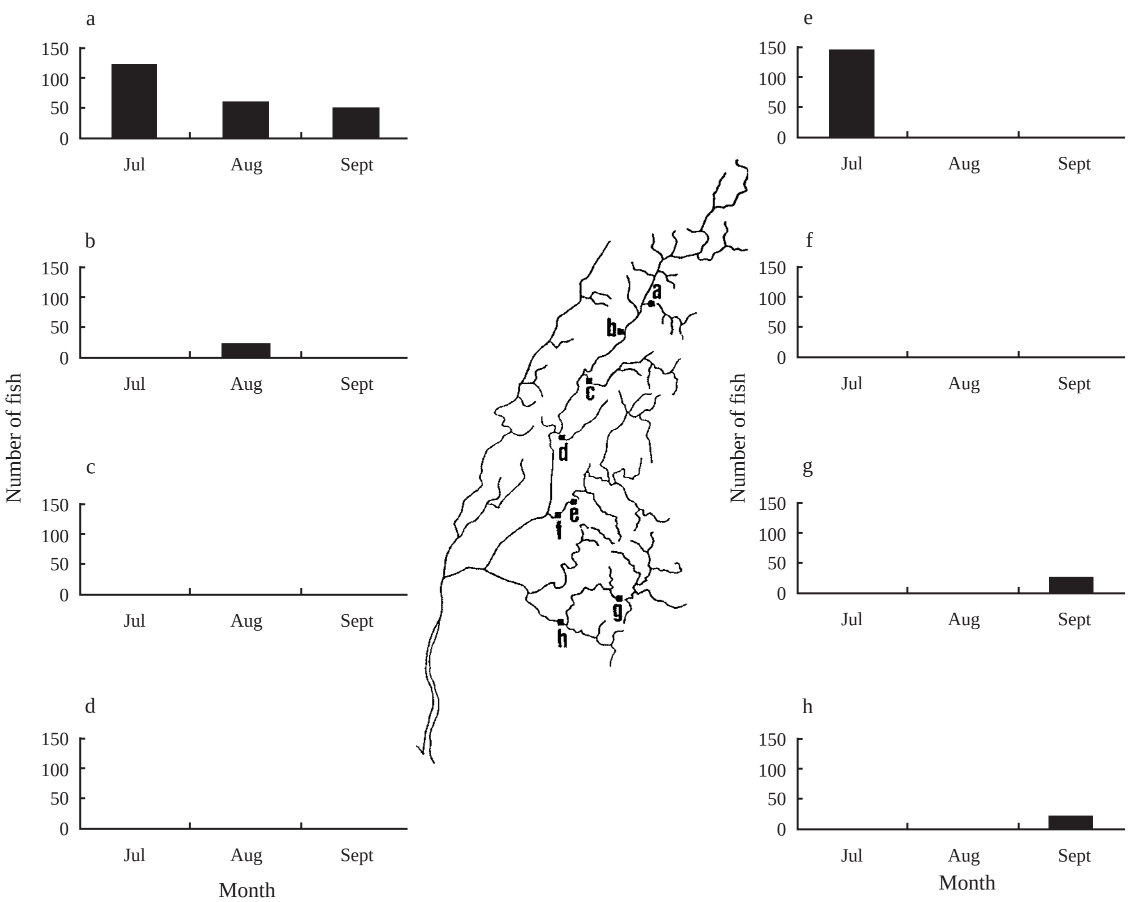

Figure 2. Variations of abundance of *V. alticorpus* at each study site from July to September 1992 (rainy season). The numbers of fish represent the combined results of hand casting, gill netting and electrofishing.

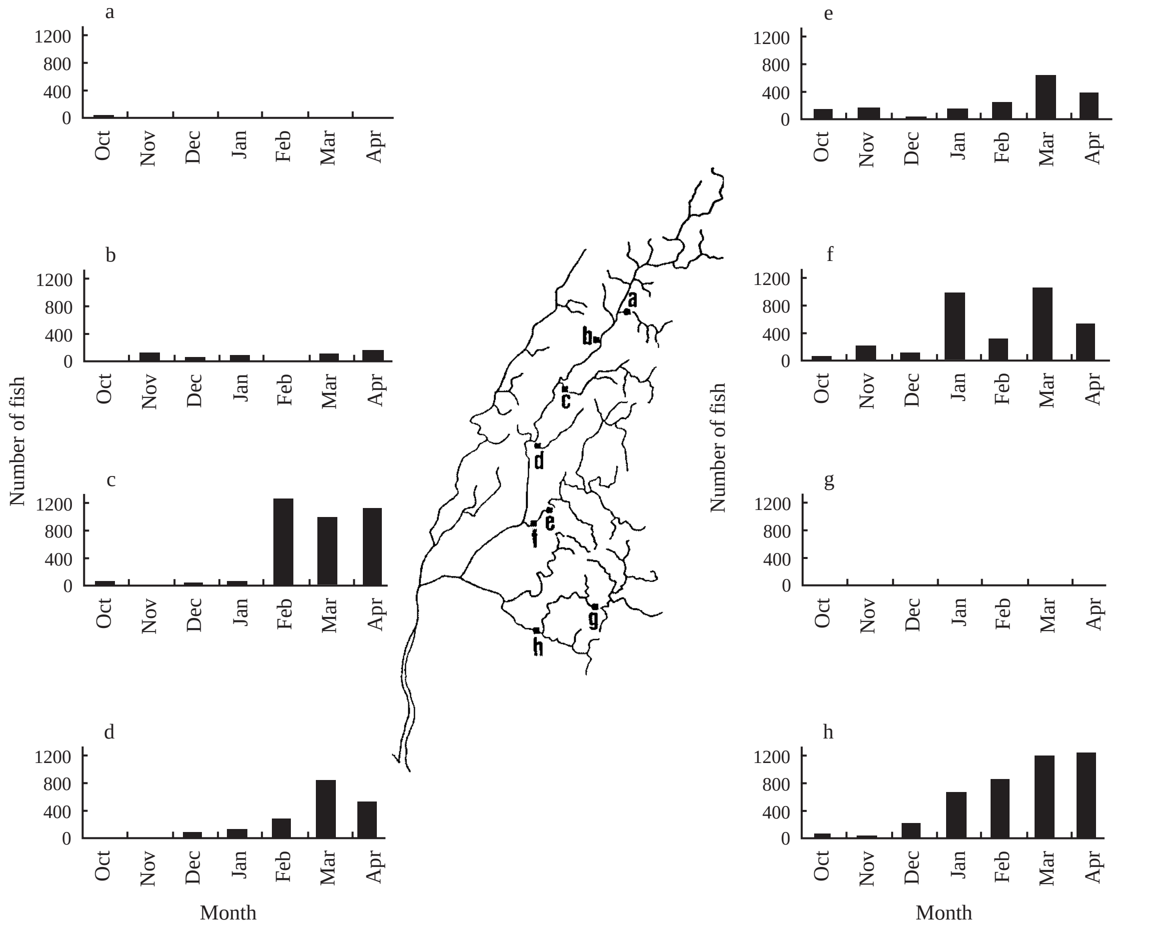

Figure 3. Variations of abundance of *V. alticorpus* at each study site from October 1992 to April 1993 (post-rainy season) as surveyed by visual census.

not successful due to poor weather conditions in the mountains.

At a given altitude, *V. alticorpus* usually schooled at sites consisting of deep pools and riffles. Different sizes of fish were found to occupy different habitats (Table 2). Most juveniles (1–3 cm) were found at the shallow flat close to the edge of a pool. Fish ranging from 3–5 cm and 5–10 cm were both found in riffles and pools, while those of sizes 10–20 cm and 20+ cm tended to occupy the pool areas. Observations during night diving showed that the fish were less active, and mostly aggregated in crevices between rocks.

Table 2. Distribution of size classes of *V. alticorpus* at different habitats (results were expressed as mean ± SD from 2 data sets which were obtained from samples conducted in November and December 1992).

Size class (cm)	Habitat			
	Riffle	Pool	Run	Shallow water flat
1–3	0	0	0	250 ± 42
3–5	116 ± 147	49 ± 43	0	0
5–10	31 ± 2	13 ± 4	0	0
10–20	9 ± 1	25 ± 15	0	0
20+	2 ± 1	21 ± 15	0	0

Feeding

Feeding behavior of the fish was recorded during daytime. When feeding on the periphyton, the fish first swam towards the rocks, then dashed downward, and shaved the periphyton off the rock using their subterminal mouths. This behavior left distinct round scars on the rock (Figure 4). The fish did not feed at night.

Analysis of the stomach contents showed that the food intake by these fish consisted mainly of diatom species, including three dominant genera such as *Cymbella*, *Tabellaria*, *Fragilaria* and 15 other less dominant genera (Table 3). Food items were similar in different seasons. Three species of insect larvae were found in the stomach contents during spring and summer. They constituted less than 1% of the total food content.

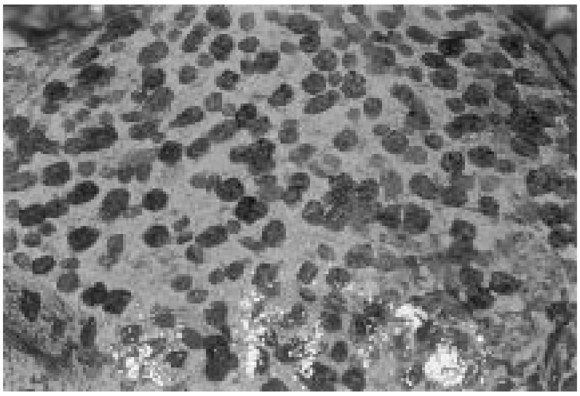

Figure 4. Round scars left by feeding *V. alticorpus*, scratching periphyton from the rocks.

Table 3. Stomach contents of *V. alticorpus* in different seasons.

	July	November	February	April
Cyanophyceae				
Oscillatoria sp.	1	1	1	1
Chlorophyceae				
Oocystis sp.	2			1
Scenedesmus spp.	1		1	1
Spirogyra sp.	1			1
Closterium sp.	1	1	1	1
Cosmarium sp.			1	1
Bacillariophyceae				
Melosira sp.		1		
Cyclotella sp.			1	1
Tabellaria spp.	3	2	3	3
Diatoma sp.	2	2	2	2
Fragilaria spp.	2	2	2	2
Synedra spp.	2	2	2	2
Cocconeis spp.	1		1	1
Cymbella spp.	4	4	4	4
Gomphonema spp.	2	1	2	2
Amphora sp.			1	1
Navicula sp.	2	2	2	2
Nitzschia sp.	1	1	1	1
Ephemeroptera				
Ecdyonurus sp.	1			
Trichoptera				
Cheumatopsyche sp.	1			1
Hydropsche sp.	1			1

1 = rare (< 10 ml^{-1}), 2 = not rich (10–50 ml^{-1}), 3 = rich but not dominant (50–1000 ml^{-1}), 4 = dominant (> 1000 ml^{-1}).

Reproduction

As shown in Figure 5, juvenile fish (1–3 cm) began to appear right after the rainy season in October and were found until February. They were found only at stations in lower altitudes.

Discussion

The rivers in Taiwan, like on many other subtropical islands, are characterized by a steep topography, which results in a short run, fast and fluctuating seasonal water flow. The strong water flow that is governed by typhoons erodes the bedrock on its way to the narrow floodplain (10–30 km wide) and creates a series of deep pools connected by riffles and runs in the mountain area. This type of habitat provides the fish not only with high levels of dissolved oxygen, but also calm feeding, resting and breeding grounds. Nevertheless, the fish still have to tolerate a wide range of dramatic environmental changes caused by typhoons, such as floods and muddy water.

V. alticorpus tended to move to the upper reaches of its range during the warm, rainy season (Figure 2) and to stay at lower altitudes during the cool, dry season (Figure 3). The increase of water always benefits fish by supplying a great variety of spawning ground and abundant food resources such as plankton, benthos and invertebrates (Junk 1985, Boujard 1992, Katano et al. 1998). In the case of *V. alticorpus*, however, the deepening of the waterways during the typhoon season could be equally important for dispersal, providing the heavily crowded juveniles of the previous winter, with a migration path to the upper parts of the stream and an opportunity there to exploit new resources.

The presence or absence of a species relates to the microhabitat of that area (Wood & Bain 1995). The substrate components in a habitat might be a more determining factor than others. In this study, *V. alticorpus* foraged during the day in riffles and pools and rested in the deep pool areas at night. These places provided both foraging and shelter for the fish. Fish were not observed to stay in run areas throughout the sampling period. The reason might be that there were no boulders and bedrock to provide proper shelters allowing the fish

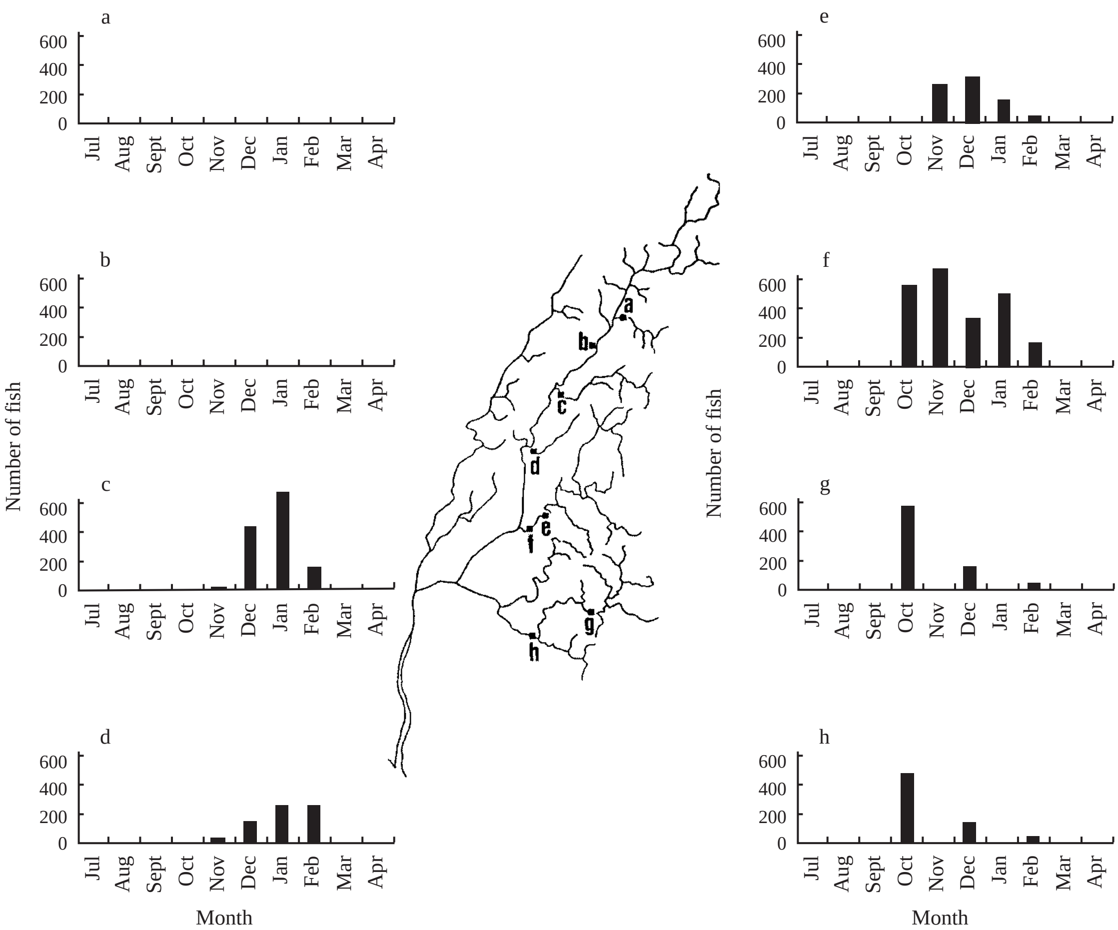

Figure 5. Number of individuals in size class 1–3 cm (juveniles) that appeared at each station from October 1992 to April 1993 (post-rainy season).

to stay in this area, and the water might be too shallow. It has been reported for the congeneric *V. barbatulus* that the net productivity was significantly related to the percentage of boulders and bedrock in its habitat (Wang 1989).

Furthermore, juveniles were found mostly at the shallow sandy-pebble flat close to the edge of pools. Since their swimming ability is weak, this area provides a habitat of low velocity flow to prevent drifting downstream (Harvey 1991). In addition, predation risk for juveniles occupying shallow areas may be lower because larger fish tend to avoid these areas (Harvey 1997).

V. alticorpus fed on the periphyton that grew on rocks in all seasons. The up-take of insect larvae was probably unintentional. *V. barbatulus*, on the other hand, fed on periphyton, filamentous algae, aquatic grass, insect larvae and adult insects (Wang 1989). Both species were found in Kaoping tributaries. Compared to the general feeding habit of *V. barbatulus*, *V. alticorpus* could be considered a specialist. *V. barbatulus* occurs at higher altitudes, more than 800 m, and sometimes higher than 2000 m. It could tolerate a water temperature lower than 10°C. The low water temperature in stream sections at high altitudes might limit the growth of periphyton. Therefore, *V. barbatulus* became adapted to a general diet when invading the upper stream with limited food resources, while *V. alticorpus* became a specialist in utilizing the abundant periphyton in the middle section of the stream.

The round feeding scars left on rocks by *V. alticorpus* are quite distinct, comparable only to the fork-like feeding scars left by *Plecoglossus altivelis* (Kawanabe & Mizuno 1989), and have not been reported before. A razorblade-like cuticle on the edge of the lower jaw creates this shaving mark. It was suggested that these scars could be used as an indication of the presence of the species.

In southern Taiwan, 90% of the 1500 mm annual precipitation falls between May and September, creating periodical floods. It has been described that the intensity of flow could adversely affect the survival of juvenile fish (Simonson & Swenson 1990, Harvey 1991, Vanderkooy & Peterson 1998). Although mating had not been observed in the field, the occurrence of 1–3 cm juveniles indicated that the reproduction of *V. alticorpus* began at the end of the rainy season (October) (Figure 5). Spawning at the end of the rainy season would have advantages. It would reduce the risk for the offspring to grow in rough conditions: not only would the young not be swept away by fast water flow, but they would also have time to grow during winter and spring to the size that can withstand the floods in the following summer. In addition the chlorophyll *a* data suggest that the periphyton at the spawning grounds grew well throughout the year and would provide plenty of food for the juveniles even in the winter. A similar timing of spawning was also reported for other local fish species (Fang et al. 1993, Wang et al. 1995) and other cyprinids in southern India (Harikumar et al. 1994).

Juvenile *V. alticorpus* occurred only at the stations of low altitude (Figure 5), suggesting that these were the spawning grounds. By examining the environmental parameters of these sites, it was likely that (1) the warmer water, usually 2–3°C higher than stations at the high altitude, (2) the slower flow, (3) the wider stream with more shallow sandy-pebble flats, and (4) the more abundant periphyton growth, would be important for the success of reproduction.

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