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原 著

Distribution of benthic insects in riffle/pool habitat in the middle reaches of the Shinano River, Japan, with emphasis on Trichoptera

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Abstract

We investigated the density and taxonomic composition of benthic insects in a 300 m section of riffle/pool habitat in the Shinano River, Japan. The most abundant taxa were Chironomidae, followed by Trichoptera. The total density of caddisflies and their contribution to the total density of benthic insects ranged from 56 to 21,744 (mean 11,644) ind. m^{-2} and from 2.6 to 44.6 (mean 29.4) %, respectively. We conducted a canonical correspondence analysis using current velocity, depth, and the ash-free dry mass of epilithon as the main factors. Benthic insect assemblages were significantly associated with the longitudinal gradient of the riffle/pool structure. *Stenopsyche marmorata* and hydropsychid species were abundant in the riffles whereas *Psychomyia acutipennis* were abundant in the pools.

Key words : Rivers, Benthic macroinvertebrates, Distribution, Riffle/pool gradient

Introduction

Caddisflies are an important group of benthic insects that play a major role in the processing of material in stream ecosystems (Mackay and Wiggins, 1979). Caddisfly species represent a large component of the richness and biodiversity in stream and river ecosystems (Wiggins 1996 ; Tanida *et al.*, 2005 ; Morse and Holzenthal, 2008 ; Wiggins and Currie, 2008). Given the importance of benthic macroinvertebrates, an understanding of their community composition and species distribution patterns is important for the conservation and restoration of river habitat.

Studies conducted in low-order streams have established that species distribution and assemblage composition of benthic macroinvertebrates reflect a riffle/pool habitat gradient (Lencioni and Rossaro, 2005 ; Davy-Bowker *et al.*, 2006). In contrast, studies of middle and high order rivers, which are deep and/or fast-flowing, are limited to measurements of species distribution at the reach or larger spatial scale (Inoue *et al.*, 2005). Previously, we evaluated the distribution of chironomid species in the riffle/pool section of a Japanese fifth-order river by identifying the adults following larval rearing. However, the emergence ratio was extremely low in that study (Inoue *et al.*, 2008b).

Our current objective was to evaluate the density and distribution of benthic insects, with emphasis on caddisflies, in riffle/pool habitat in the middle reach of a river.

Materials and Methods

The study was conducted on the middle reaches of the Shinano River (**Fig. 1** ; 36°25′40″N, 138°11′19″E), the longest river in Japan (367 km). We collected larval samples and measured environmental variables between 30－31 January, 2006 at riffle/pool sites in the town of Sakaki, Nagano Prefecture, Japan.

We selected five sites in the reach, distributed along a riffle/pool gradient (**Fig. 1**). We measured current velocity, water depth, and the ash-free dry mass (AFDM) of epilithon. We quantified the AFDM by drying the epilithon at 105℃ for 5 h then burning the sample at 450℃ for 30 min. We also measured the particle composition of the substrate and the landscape

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at each site.

Benthic samples were collected using a Surber net (30 × 30 cm², 450 μm mesh) and fixed in 10% formalin. The macroinvertebrates were sorted and counted under a binocular dissecting microscope (max. 40×) and identified to the order or family level. We identified the major Trichopteran species following the descriptions of Tanida *et al.* (2005).

We evaluated the relationships between the benthic macroinvertebrate assemblage and the three environmental variables using a Canonical Correspondence Analysis (CCA ; Ter Braak, 1986) in CANOCO 4.5 for Windows (Ter Braak and Smilauer, 2002). We used biplot scaling with a focus on inter-species distances to the relationship between species distribution and the environmental variables. The data were untransformed although rare species were down-weighted. We evaluated the significance of the first and the sum of all canonical axes using Monte Carlo permutation tests (1,000 runs).

Results and Discussion

The values for the environmental indices at the five study sites ranged from 61.2 (St. 3) to 128.2 (St. 2) cm s^{-1} for current velocity, from 9.5 (St. 1) to 48.6 (St. 4) cm for depth, and 36 (St. 1) to 204 (St. 4) g m^{-2} for the AFDM (**Table 1**). The substrates consisted primarily of pebbles and cobbles at all study sites, except St. 3 where gravel and sand were abundant. We defined St. 1 and 2 as riffles, St. 4 and 5 as pools, and St. 3 as a transition site from riffle to pool.

We collected a total of 17,833 individuals (mean density for the 5 sites : 39,629 ind. m^{-2}) belonging to 5 orders of Insecta. The most abundant taxon was Chironomidae (37.4 % of total abundance), followed by Trichoptera (29.4 %), Ephemeroptera (28.4 %) and Simuliidae (3.3%) (**Table 2**). Trichoptera accounted for 44.6% of the total abundance at St. 4 but only 2.6% at St. 3. We collected 5 trichopteran families of which Hydropsychidae was the most abundant, followed by

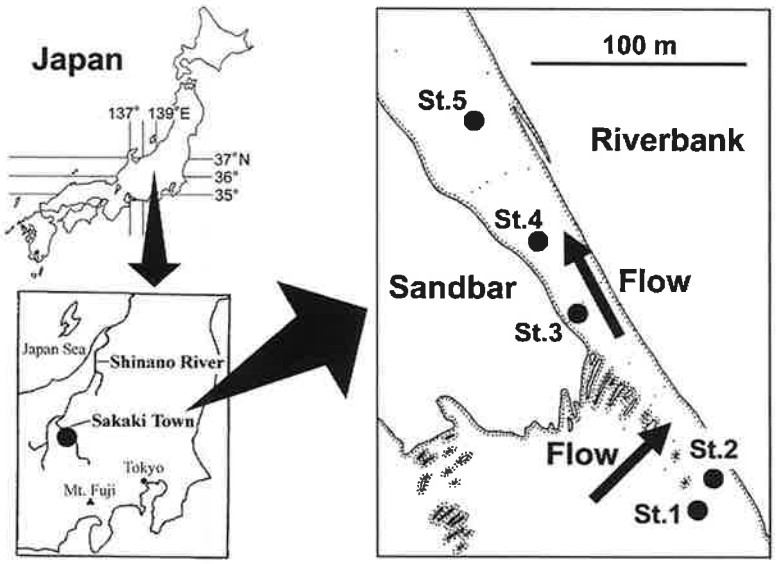

Fig. 1. Map of the Shinano River showing the location of the study site (left). Five stations were selected in a riffle/pool section (right).

Table 1 Environmental measurements for the five study sites in a riffle/pool section of the middle reaches of the Shinano River.

Measurements	St. 1	St. 2	St. 3	St. 4	St. 5
Current (cm s^{-1})	106.1	128.2	61.2	82.9	63.3
Depth (cm)	9.5	44.9	22.0	48.6	43.4
AFDM (g m^{-2})	36	152	84	204	172

AFDM : ash-free dry mass.

Psychomyiidae and Stenopsychidae. The Hydropsychidae included several species, the most abundant of which was *Hydropsyche orientalis* Martynov. The Psychomyiidae and Stenopsychidae were represented exclusively by *Psychomyia acutipennis* (Ulmer) and *Stenopsyche marmorata* Navás, respectively. Both Hydropsychidae and Stenopsychidae (*S. marmorata*) were abundant at St. 1 and 2 whereas Psychomyiidae (*P. acutipennis*) was abundant at St. 4. Rhyacophilidae and Hydroptilidae were only rarely collected. In relation to taxa than other Trichoptera, Simuliidae were only collected at St. 1 and 2 and Ephemeroptera were abundant at St. 1 and 2.

Both the first canonical axis (Axis 1) ($p = 0.043$, Monte Carlo permutation test 1,000 runs) and the sum of all the axes ($p = 0.026$) of the ordination were significant. The first two axes were used to explain the species distribution pattern. These explained 98.3 % of the variance in the species data and 99.1 % of the species-environment relationship (**Table 3**). The relationship between sites and environmental variables revealed that depth and AFDM were positively associated with

Table 2 Densities (ind. m^{-2}) of insect taxa collected at five sites in riffle/pool habitat in the middle reaches of the Shinano River.

Taxon	St. 1	St. 2	St. 3	St. 4	St. 5	Mean
Coleoptera	11	22	—	11	—	9
Diptera	(13,544)	(30,433)	(2,033)	(24,978)	(12,422)	(16,682)
Ceratopogonidae	—	—	—	11	—	2
Chironomidae	8,856	26,622	2,011	24,278	12,344	14,822
Simuliidae	4,500	3,100	—	—	—	1,520
Tipulidae	189	711	22	689	78	338
Ephemeroptera	24,644	29,033	33	1,944	644	11,260
Odonata	89	33	—	44	—	33
Trichoptera	(16,289)	(18,689)	(56)	(21,744)	(1,444)	(11,644)
Hydropsychidae	15,344	15,678	—	3,444	167	6,927
Hydroptilidae	—	—	—	—	11	2
Psychomyiidae	289	1,911	56	18,211	1,267	4,347
Rhyacophilidae	—	111	—	11	—	24
Stenopsychidae	656	989	—	78	—	344
Total	54,578	78,211	2,122	48,722	14,511	39,629
Chironomidae %	16.2	34.0	94.8	49.8	85.1	37.4
Ephemeroptera %	45.2	27.1	1.6	4.0	4.4	28.4
Trichoptera %	29.8	23.9	2.6	44.6	10.0	29.4

Table 3 Eigenvalues for CCA.

	CCA axes			
	1	2	3	Total inertia
Eigenvalue	0.410	0.079	0.004	0.497
Species-environment correlation	0.995	1.000	0.994	
Cumulative % variance				
Of species data	82.4	98.3	99.2	
Of species-environment relation	83.1	99.1	100.0	
Sum of all eigenvalues				0.497
Sum of all canonical eigenvalues				0.493

Axis 1, whereas current velocity was negatively associated (**Fig. 2**). In addition, the riffle sites had low scores on Axis 1 whereas pool sites had higher scores on Axis 1. St. 3 scored close to 0 on Axis 1, but had scored higher on Axis 2 than the remaining sites. Thus, we concluded that Axis 1 represented the riffle/pool gradient. We were unable to find a reasonable interpretation for Axis 2, but it likely represents an environmental gradient such as substrate size.

The taxa with low Axis 1 scores (e.g. Stenopsychidae (*S. marmorata*), Hydropsychidae, Simuliidae and Ephemeroptera) were abundant in the riffle. Conversely, taxa with higher Axis 1 scores (Psychomyiidae (*P. acutipennis*)) were more abundant in the pool. Interestingly, the CCA analysis suggested that Chironomidae were more abundant in the pool. However, their density was highest at a riffle site (St. 2), followed by a pool site (St. 4). In addition, because as many as 92 species were recorded in the mid reaches of the Shinano River (Inoue *et al.*, 2008a), differences in distribution patterns in riffle/pool and other environmental gradients should be analyzed at the species-level (Inoue *et al.*, 2005 ; 2008b).

Our study documented the distribution of benthic insects along a riffle/pool gradient in the mid reach of a river. Previous studies, conducted primarily in the upper reaches of rivers and streams, also noted that *S. marmorata* is common in Japan and is typically abundant in riffles (Tanida *et al.*, 2005). The larvae of *S. marmorata* spin feeding nets in interstices between riverbed stones to filtrate suspended organic matter. Thus, both the high current velocity and rough riverbed substrate at St. 1 and 2 are requisite for colonization by this species. We collected several Hydropsychidae species that spin feeding nets and were also abundant at St. 1 and 2. *Hydropsyche* species occupy high velocity riffles (Yamagishi, 1977 ; Wiggins, 1996 ; Tanida, 2007), but smaller numbers were also collected at pool sites, suggesting that the larvae can tolerate lower current velocities than *S. marmorata*. Conversely, the density of *P. acutipennis* was highest at St.4. The larvae of *P. acutipennis* construct nesting tubes of fine silk and this species is typically abundant in areas of low current velocity (Yamagishi, 1977 ; Hirabayashi *et al.*, 2005 ; Kimura *et al.*, 2009). Our results suggest that the nesting tubes of *P. acutipennis* may not withstand high current velocity. However, the larvae likely have low feeding efficiency in areas of low velocity.

The scale of riffle/pool structures is much larger in the middle reaches of a river than the upper reaches. However, we found similarities in the distribution patterns of insect taxa in both the middle and upper reaches. In the future, we intend to investigate the effects of the riffle/pool gradient on distribution at the species level.

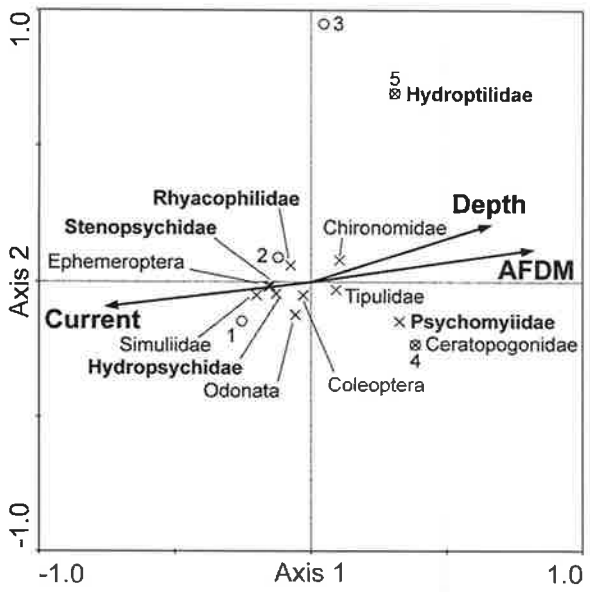

Fig. 2. CCA ordination diagram of insect taxa (crosses), samples (circles) and environmental variables (arrows).

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信濃川中流域の瀬—淵1区間における底生昆虫類の分布：特にトビケラ目について

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信濃川中流域における約 300 m の瀬—淵1区間で、底生昆虫類の個体密度と分類群組成を調査した。個体密度ではユスリカ科が最も高く、次いでトビケラ目の順であった。トビケラ目の個体密度は 56～21,744（平均 11,644）個体／mg であり、全底生昆虫類の 2.6～44.6（平均 29.6）%を占めた。最終地点の流速、水深、河床付着物の強熱減量を環境要因とした正準対応分析の結果、底生昆虫類の分類群組成と瀬—淵の環境勾配との間に有意な相関が認められた。ヒゲナガカワトビケラ *Stenopsyche marmorata* およびシマトビケラ科は主に瀬に多く分布したのに対し、ウルマークダトビケラ *Psychomyia acutipennis* は淵に多く分布した。