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Original Artcle

Changes in the species composition and density of caddisflies (Trichoptera) after an excavation work in the middle reaches of the Shinano River, Japan

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Abstract

We evaluated the effect of riverbed excavation on the macroinvertebrate community in the middle reaches of the Shinano River, Japan. Macroinvertebrate samples were collected at a treatment site, created by excavation of the riverbed, over a 98 d period. We compared the density and diversity of caddisfly larvae collected at the treatment site to a control site, located upriver. Three of 10 species found at the control site were not found at the treatment site. Furthermore, the Shannon-Wiener species diversity index (H') was lower at treatment site, although the total caddisfly density was similar to the control site by Day 98. The three most abundant species at control site were *Psychomyia acutipennis, Potamyia chinensis, and Hydropsyche orientalis.* The density of all three species was initially low at the treatment site following the excavation (Day 1). Beginning at Day 69, the density of *Ps. acutipennis* began to increase at the treatment site and was more than twice as high as at the control site by Day 98. Similarly, the density of *Po. chinensis* increased between Day 59 and 98 but did not exceed the density at the control site. In contrast, *H. orientalis* was rarely observed at the treatment site. Our results suggest that large-scale removal of the riverbed affected several key physical parameters and changed the density and species diversity of the trichopteran community.

Key words : Caddisfly, Diversity, Large-scale substrate removal, Recovery, Shinano River

Introduction

Colonization by benthic macroinvertebrates has attracted considerable attention (Mackay, 1992) among researchers studying the dynamics of populations and communities in lotic ecosystems (Fisher, 1983 ; Sheldon, 1984 ; Resh *et al*., 1988). Experimental studies evaluating recolonization following small-scale removal or replacement of substrate have shown that the density and diversity of benthic macroinvertebrate species reach an equilibrium within a few weeks (Townsend and Hildrew, 1976 ; Lake and Doeg, 1985; Hayashi, 1991 ; Mackay, 1992). In contrast, a smaller number of studies, investigating large-scale habitat modification, have shown that recovery may take several months (Gore, 1979, 1982).

Recovery of communities from natural and artificial disturbances deserves consideration during the environmental assessment process (Niemi *et al*., 1990). Flood control projects often involve protection from bank-side erosion and channel excavation to maintain high discharge capacity. Such projects often result in modification of the local topography and removal of organisms, especially benthic macroinvertebrates, from the disturbed area. Despite this, there has been little effort to evaluate the impact of such modifications on species composition and density by comparing the newly created habitat to the surrounding area. Such information is critical to reduce the impact of habitat modification projects on natural communities.

Caddisflies are one of the most diverse animal

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groups within lotic ecosystems, and their larvae are typically the most abundant in lotic habitats (Wiggins, 1996 ; Tanida *et al.*, 2005 ; Morse and Holzenthal, 2008 ; Wiggins and Currie, 2008). They are also one of the most important secondary producers in lotic ecosystems (Mackay and Wiggins, 1979). Our objectives were to evaluate the time required for recovery of the benthic macroinvertebrate community and describe the pattern of recolonization following large-scale removal of riverbed substrate for the purpose of flood control. We measured the species diversity and density of caddisflies in a natural riffle and in a recently excavated section of the Shinano River, Japan.

Materials and methods

Study sites

The study was conducted in a reach of the fifth-order section of the Shinano River (Chikuma City, Nagano Prefecture ; 36° 32′ N, 138° 07′ E ; 355 m a.s.l.) (**Fig. 1**). The Shinano River is the longest river in Japan (367 km) and has a catchment of 11,900 km^2. To maintain a high discharge capacity during flood events, a section of the riverbed within our study site was excavated between December 15, 2005 and March 27, 2006. This involved the removal of 14,800 m^3 of the substratum within a 17,000 m^2 area of the riverbed

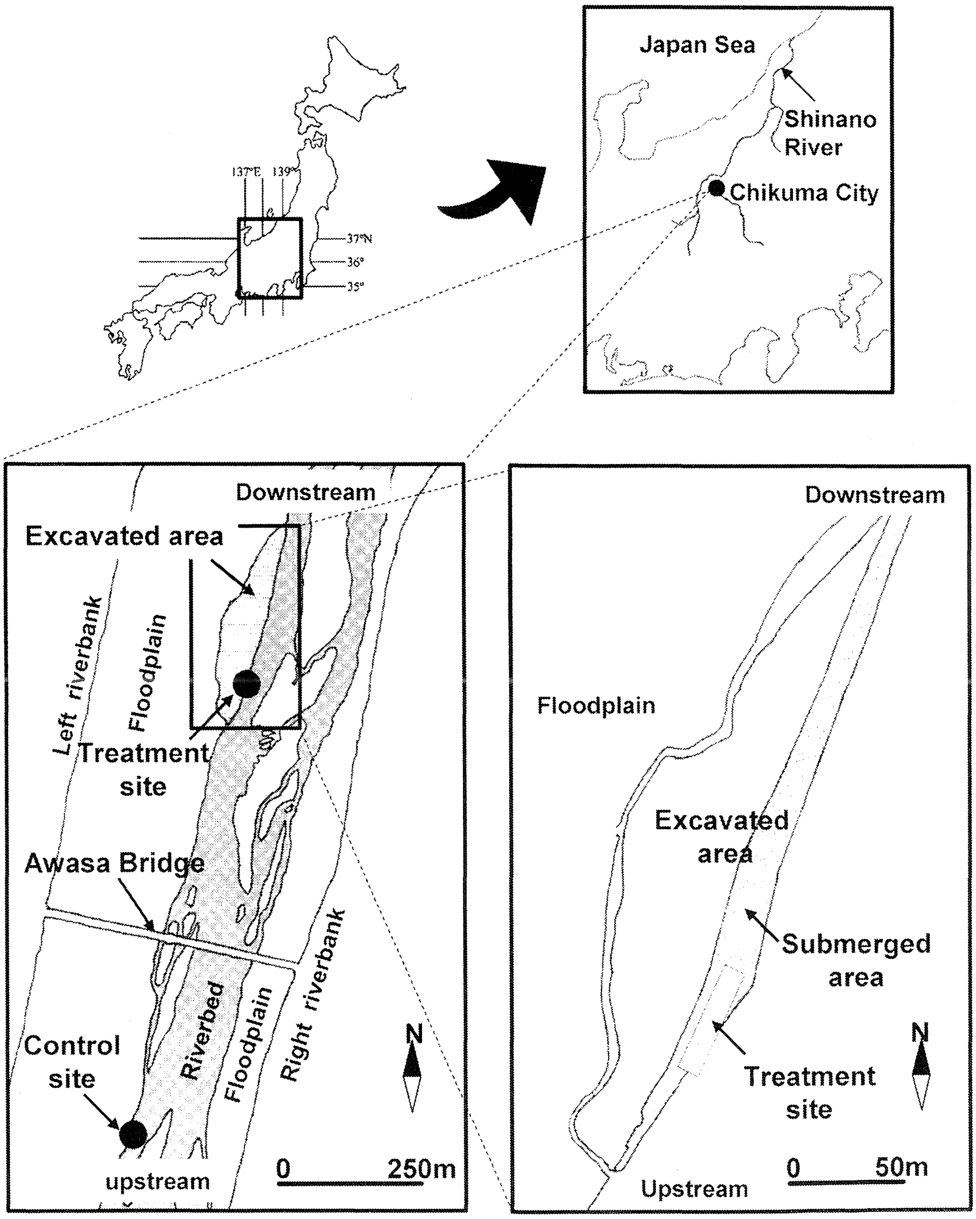

Fig. 1. Map of the middle reaches of the Shinano River showing the sampling site locations.

and floodplain along 350 m of the left riverbank. Following excavation, an area of 2,800 m^2 was submerged during normal discharge conditions. The newly submerged area resembled a riffle, although the current velocity was slower than in the surrounding area.

We selected two study sites within the reach to monitor trichopteran communities. The first (treatment) site was located within the submerged section of the excavated area and the second (control) site was located in a natural riffle 800 m upstream of the excavated area. Prior to excavation the treatment site was covered by a dense thicket of invasive plant species consisting primarily of star-cucumber, *Sicyos angulatus* L., and giant ragweed, *Ambrosia trifida* L. In addition, the river-bank at this point formed a steep cliff several meters in height. Thus we were not able to access the riverbed at the treatment site prior to the excavation. However, analysis of the topography at the treatment site prior to excavation suggests that flow conditions were similar to the control site.

Sampling and identification of caddisflies

We collected benthic caddisfly samples between March 28 (1 d after completion of the excavation work : Day 1) and July 3 (Day 98), 2006 at the treatment site and between March 21 (Day -6) and July 31 (Day 126), 2006 at the control site (**Table 1**). Samples were collected by removing a single stone (cobble size) from the riverbed in front of a Surber net (30×30 cm^2 frame opening ; 450 μm mesh). The stone was then held in the net and the surface was scraped with a sponge to remove the organic matter and attached organisms. The samples were then transferred into a polyethylene bag and immediately fixed in 10% formalin. The surface area of the cobble was calculated by measuring the length, width, and height of the cobble to the nearest mm using a vernier caliper (Standard Model, Mitsutoyo Corp., Kanagawa, Japan). This procedure was repeated 10 times at randomly selected locations within in a fixed area (~ 50×10 m^2) at the two study sites on each sampling date. The treatment site was located in a section of the river that was also submerged prior to the excavation

Table 1 Sampling dates at the treatment and control sites. Open and solid diamonds represent the sampling dates at control site before and after the study period respectively at the treatment site.

Date in 2006	Number days after the riverbed excavation work	Treatment site	Control site
Mar. 21	Day -6		◇
Mar. 28	Day 1	○	○
Mar. 30	Day 3	○	
Apr. 01	Day 5	○	
Apr. 04	Day 8	○	
Apr. 07	Day 11	○	
Apr. 10	Day 14	○	○
Apr. 15	Day 19	○	
Apr. 18	Day 22	○	
Apr. 24	Day 28	○	○
May. 01	Day 35	○	
May. 09	Day 43	○	○
May. 17	Day 51	○	
May. 25	Day 59	○	○
Jun. 04	Day 69	○	○
Jun. 20	Day 85	○	○
Jun. 03	Day 98	○	○
Jun. 31	Day 126		◆

(Fig. 1). In addition, a qualitative benthic sample was collected so that larval caddisflies could be reared to adulthood. This enabled identification in cases where the larvae could not be identified to the species level.

All caddisflies in the samples were identified to the species level, based on the taxonomical keys of Wiggins (1996) and Tanida *et al.* (2005), and counted using a binocular dissecting microscope. Some larvae could only be identified to the genus level. In these cases, the species name was inferred from the adults obtained following rearing of the larval samples.

Environmental measurements

We measured water quality at the study sites on each sampling date using portable meters. The parameters included dissolved oxygen concentration (DO-24P : DKK-TOA Corp., Tokyo, Japan), electric conductivity, pH (WM-22EP : DKK-TOA Corp., Tokyo, Japan) and water temperature. We also measured the current velocity and water depth above each cobble, collected during the invertebrate sampling, using an electro-magnetic current meter (VE-10 : Kenek Co. Ltd., Tokyo, Japan) and ruler, respectively. In addition, river discharge data was provided by the Chikuma River Office, Hokuriku Regional Development Bureau (Ministry of Land, Infrastructure, Transport and Tourism, unpublished).

Data analyses

The number of caddisfly species on each sampling date was expressed as the total number collected from the 10 (replicate) cobbles at each site. We also calculated the Shannon-Wiener diversity index (H') using the total abundance of each caddisfly species collected on each sampling date. The caddisfly density was expressed as the number of individuals per unit surface area of cobbles. The surface area S (cm^2) of a cobble was calculated using the following formula (Graham *et al.*, 1988):

$$S = 1.15\ (LW + WH + HL)$$

where L, W, and H are the length, width, and height of the cobble, respectively, in cm.

All statistical tests were performed in SPSS version 11.5.1J for Windows (SPSS Japan Inc., Tokyo, Japan).

Results

Environmental conditions

The physicochemical conditions were generally similar between the two study sites, however, current velocity was significantly lower at the treatment site than at the control site (Mann-Whitney U test, $p < 0.001$) **(Table 2)**. The riverbed at both sites was composed primarily of cobbles. The length and the surface area of the cobbles sampled at the treatment site were significantly smaller than at the control site (Mann-Whitney U test, $p < 0.001$). Furthermore, electric conductivity was significantly higher at the control site (Mann-Whitney U test, $p = 0.019$), although the difference in values was negligible. The daily mean discharge in the reach ranged between 25.2 and 153.7 (mean: 43.2 ± 19.9) $m^3\ s^{-1}$. The discharge was relatively constant between Day -10 and Day 111 **(Fig. 2)**. However, a flood event was recorded on Day 112 (peak daily mean discharge : 2,060.8 $m^3\ s^{-1}$). The flood caused severe erosion of the riverbed and

Table 2 Environmental measurements at the sampling sites between Day 1 and Day 98.

	Treatment site		Control site	
	n	Mean ± SD	n	Mean ± SD
Water temperature (℃)	16	15.3 ± 5.3	8	18.7 ± 5.7
pH	16	8.59 ± 0.35	8	8.23 ± 0.55
Electric conductivity (mS m^{-1})	16	16.50 ± 1.51[a]	8	17.99 ± 1.39[b]
Dissolved oxygen (mg L^{-1})	16	12.95 ± 2.11	8	11.57 ± 1.55
Water depth (cm)	160	23.7 ± 5.9	80	24.9 ± 4.6
Current velocity (cm s^{-1})	160	36.8 ± 7.5[a]	80	126.2 ± 17.4[b]
Substrate length (cm)	160	11.8 ± 2.1[a]	80	12.8 ± 2.2[b]
Surface area of substrate (cm^2)	160	247.5 ± 83.3[a]	80	290.2 ± 91.8[b]

a, b : Vaules with different superscript in the same row were significantly different from each other (Mann-Whitney U test, $p < 0.05$).

floodplain at the treatment site. Thus we were not able to collect samples at the treatment site following the flood.

Species composition and diversity of caddisflies

Ten caddisfly species, belonging to six families, were collected at the two study sites (**Table 3**). The most abundant species at the control site was *Potamyia chinensis* (29.7% of the mean density), followed by *Hydropsyche orientalis* (27.8%) and *Psychomyia acutipennis* (25.3%). In contrast, the three most abundant species at treatment site were *Ps. acutipennis* (67.9%), *Po. chinensis* (18.8%), and *Stenopsyche marmorata* (10.1%). All seven species that were collected at the treatment site were also found at the control site. Conversely, *Glossosoma ussuricum, Cheumatopsyche infascia*, and *Hydropsyche setensis* were found only at the control site, although not in large numbers.

The number of caddisfly species ranged between 7

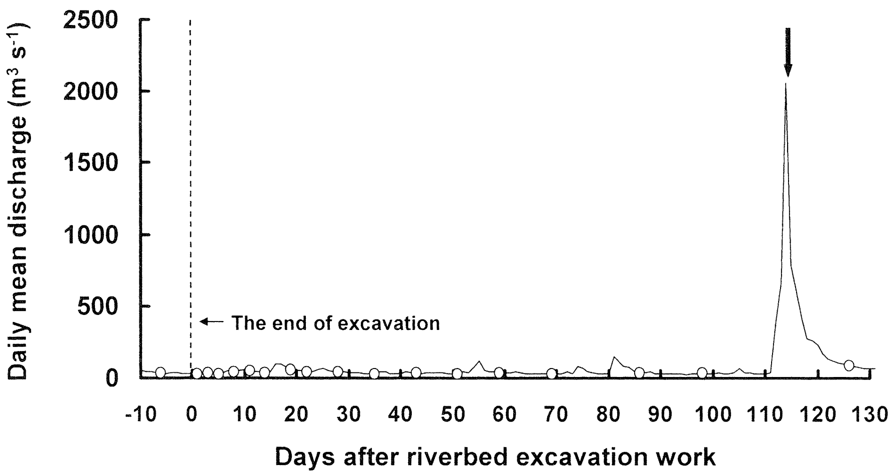

Fig. 2. Daily mean discharge during the study period. Data provided by the Ministry of Land, Infrastructure, Transport and Tourism. Open circles: Sampling dates. Arrow: peak discharge during the flood.

Table 3 Mean density (ind. m^{-2} ± SD) of caddisfly species collected at the two sites between Day 1 and Day 98.

	Treatment site (n = 160)		Control site (n = 80)	
	Mean ± SD	%	Mean ± SD	%
Rhyacophilidae				
Rhyacophila yamanakaensis Iwata	2.5 ± 2.8	0.5	15.5 ± 5.6	0.5
Hydroptilidae				
Hydroptila sp.	4.7 ± 5.0	1.0	5.8 ± 8.3	0.2
Glossosomatidae				
Glossosoma ussuricum (Martynov)			0.5 ± 1.5	0.02
Stenopsychidae				
Stenopsyche marmorata Navás	49.8 ± 18.5	10.1	265.6 ± 89.7	9.4
Psychomyiidae				
Psychomyia acutipennis (Ulmer)	333.4 ± 56.5	67.9	714.2 ± 165.6	25.3
Hydropsychidae				
Cheumatopsyche brevilineata (Iwata)	0.3 ± 0.8	0.1	167.1 ± 44.4	5.9
Cheumatopsyche infascia Martynov			4.3 ± 5.1	0.2
Hydropsyche orientalis Martynov	7.9 ± 6.5	1.6	785.5 ± 145.2	27.8
Hydropsyche setensis Iwata			24.8 ± 5.7	0.9
Potamyia chinensis (Ulmer)	92.5 ± 46.2	18.8	839.5 ± 207.1	29.7
Total No.	491.2 ± 46.0	100.0	2,822.8 ± 293.4	100.0
No. of families	5		6	
No. of genera	7		8	
No. of species	7		10	

and 9 at the control site and was relatively constant during the study (**Fig. 3**). In contrast, species diversity was more variable at the treatment site. Only 1 species was found at the treatment site on Day 1. However, diversity increased gradually up to Day 69 then remained constant and was always lower than at the control site. Similarly, the Shannon-Wiener index (H') was highly variable at the treatment site prior to Day 28. Following this, the index increased gradually up to Day 69, then decreased. H' at the treatment site never exceeded H' at the control site.

Changes in caddisfly density

The surface area of the cobbles ranged between 120.2 and 518.2 cm^2 at the treatment site (mean : 247.5 ± 83.3), and between 111.6 and 612.5 cm^2 (mean : 290.2 ± 91.8) at the control site (**Table 2**). Total caddisfly density at the control site ranged between 1,278.6 ± 816.8 and 3,097.3 ± 1,484.0 ind. m^{-2}, and was always higher than at the treatment site (**Fig. 4**). Total caddisfly density was extremely low at the treatment site immediately after the excavation work was completed. However, the density increased gradually thereafter and by Day 98 was similar to that at the control site (Mann-Whitney U test, $p = 0.143$).

Following the flood, which occurred two weeks after the last sampling date at the treatment site (Day 98), total caddisfly density decreased sharply at the control site. We were not able to collect caddisfly samples at the treatment site following the flood.

The density of three most abundant species at the control site was very low at the treatment site immediately after the excavation. The density of *Ps. acutipennis* ranged between 220.9 ± 328.9 and 1,108.6 ± 445.8 ind. m^{-2} at the control site, and was less variable than at the treatment site (**Fig. 4**). After Day 69, the density of *Ps. acutipennis* at the treatment site increased rapidly was more than twice as high as at the control site by Day 98.

The density of *Po. chinensis* at the control site ranged between 254.4 ± 382.3 and 1,787.1 ± 746.7 ind. m^{-2} prior to the flood (**Fig. 4**). In contrast, the density at the treatment site was $<$ 20 ind. m^{-2} up to Day 59 and then increased rapidly to 747.2 ± 550.9 ind. m^{-2} by Day 98. However, the density of *Po. chinensis* at the treatment site never exceeded the density at the control site.

The density of *H. orientalis* ranged between 277.3 ± 169.8 and 1,787.1 ± 746.7 ind. m^{-2} at the control site. The density was much lower at the treatment site,

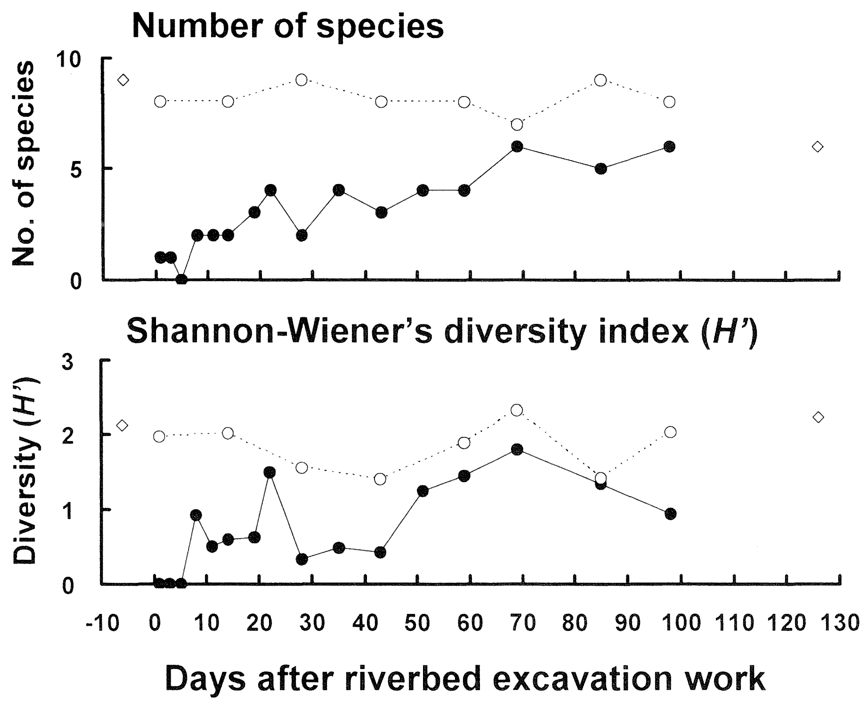

Fig. 3. Changes in the number of caddisfly species and the caddisfly species diversity index (H') during the study period. Solid circles: treatment site, open circles : control site, open diamonds : control site (Day -6 and 126).

peaking at 55.5 ± 85.0 ind. m^{-2}, and we often found no evidence of this species at the treatment site.

Discussion

The scale of riverbed modification is an important factor in determining the time needed for recovery of macroinvertebrate communities (Wallace, 1990 ; Mackay, 1992). The flood protection project in the Shinano River created 2,800 m^2 of new aquatic habitat following the removal of 14,800 m^3 of substratum. We found that the caddisfly density recovered within 98 d of completing the excavation. Similar studies have evaluated the colonization of lotic macroinvertebrates after small-scale removal of the river-bed in riffles. The time taken for recovery of macroinvertebrate density ranged between 1 d, after 10 × 50 cm^2 removal (Doeg *et al.*, 1989), to 38 d, after 18 × 37 cm^2 removal (Townsend and Hildrew, 1976), and was usually in the range of 10-25 d (Minshall and Petersen, 1985). In all instances, the duration of recovery was much shorter than in our study (Hayashi, 1991 ; Mackay, 1992). However, the difference in recovery time is smaller than the difference in the scale of riverbed excavation.

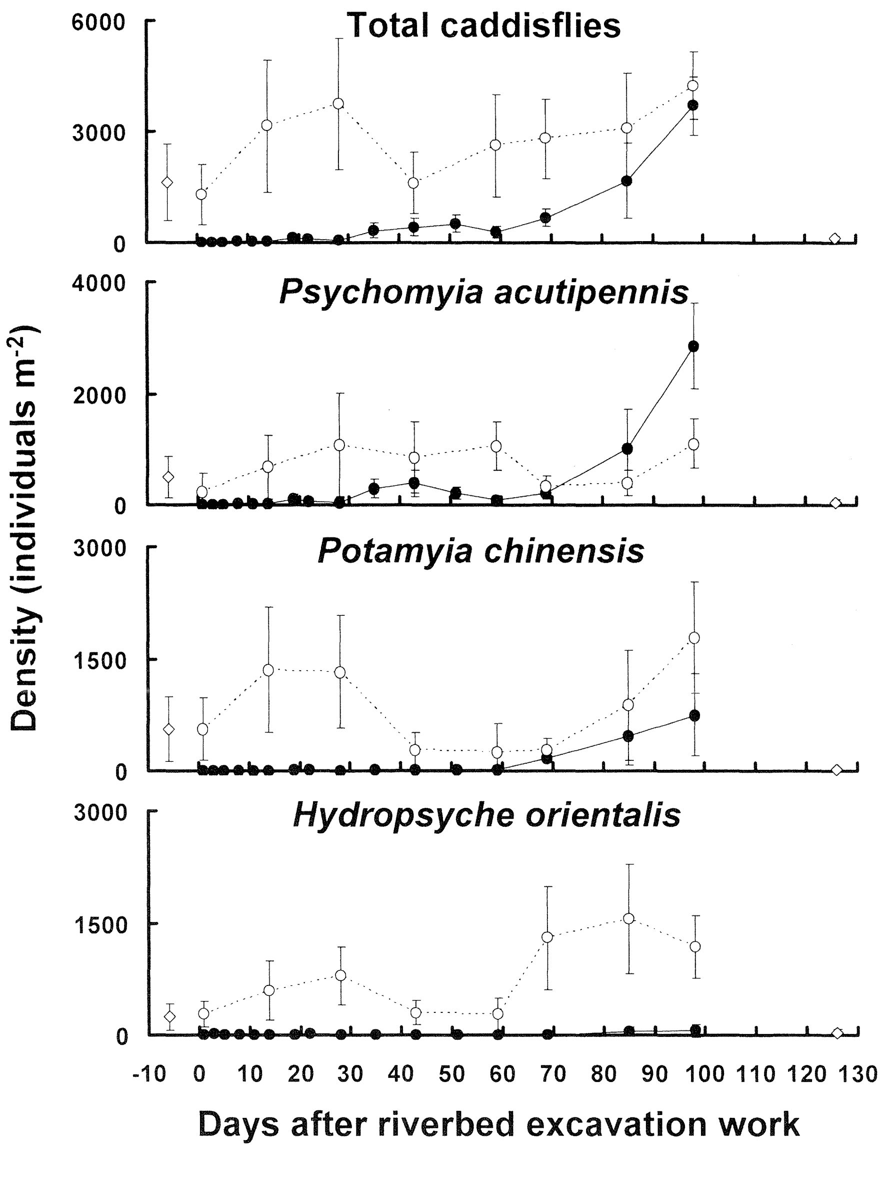

Fig. 4. Changes in mean (± SD) caddisfly density during the study. Solid circles: treatment site, open circles: control site, open diamonds: : control site (Day -6 and 126).

This suggests that the time required for recovery increases logarithmically with the scale of riverbed removal.

Although caddisfly density recovered within 98 d at treatment site, we found that the species diversity differed significantly from the control site throughout. We noted the disappearance of three rare species at the treatment site, and species diversity was always lower than at the control site. Our data suggests that complete recovery of the trichopteran community may take considerably longer than 98 d following such large scale habitat modifications. Among the three most abundant species at the control site, the density of *Ps. acutipennis* increased rapidly towards the end of the study at the treatment site, exceeding the density at the control site by a factor of two. *Psychomyia* larvae are small in size (Tanida *et al.*, 2005) and are typically abundant in riffles that have relatively low current velocities (Yamagishi, 1977) and in low velocity sand-filter beds using for filtration of drinking water (Hirabayashi *et al.*, 2005). The small size, relatively short life cycle, and low current velocity are likely to have contributed to the rapid colonization of *Ps. acutipennis* at the treatment site. Because of the lower current velocity at the treatment site, it is unlikely that the density of *Ps. acutipennis* would have stabilized at a similar level to the control site. In contrast, *H. orientalis* was rarely found at the treatment site throughout the study. The larvae of *Hydropsyche* occur in high velocity riffles (Yamagishi, 1977 ; Wiggins, 1996 ; Tanida, 2007). Thus the lower current velocity at the treatment site is likely to have inhibited colonization by *H. orientalis*. The increase *Po. chinensis* density at treatment site towards the end of the study emphasizes the influence of current velocity on the recovery of this trichopteran community. *Potamyia* species are typically more abundant in slow moving water than *Hydropsyche* species (Wiggins, 1996).

We were not able to evaluate the environmental conditions or the density and species composition of caddisflies at treatment site prior to the excavation. However, we believe that excavation may have altered the size distribution of the riverbed substrate. Thus it is plausible that the changes we observed in the caddisfly population may also be due to changes in the size composition of the riverbed substrate.

In summary, our results suggest that changes in hydrology due to modification of the local topography affected the recovery of the trichopteran community following excavation. The habitat created by the excavation work differed from the surrounding area, particularly with respect to the current velocity. We also noted that the treatment site suffered severe erosion during the flood. This would have led to further changes in the habitat and delayed recovery. Therefore, in the long-term the impact of river conservation efforts on benthic macroinvertebrate communities will be dependent on the effectiveness of such projects at preventing further erosion and habitat damage.

Acknowledgments

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信濃川中流域における河道掘削後のトビケラ類個体密度と種組成の変化

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2005 年 12 月から 2006 年３月にかけて，信濃川中流域において大規模な河道掘削が行われた．本研究では，掘削された地点（掘削区）と上流側の掘削されていない地点（対照区）の２地点において，トビケラ類の個体密度と種組成の変化に注目し調査を行った．対照区で捕獲された合計10種のトビケラ類のうち３種は掘削区において捕獲されず，掘削区における種多様度指数 H' は対照区より低かった．しかし，掘削区におけるトビケラ類の総個体密度は掘削から 98 日後に対照区の密度にまで回復した．対照区において捕獲数の多かった３種のうち，ウルマークダトビケラ *Psychomyia acutipennis* の個体密度は掘削区において急激に増加し，掘削から 98 日後には対照区の２倍以上に達した．掘削区ではエチゴシマトビケラ *Potamyia chinensis* の個体密度も増加したが，対照区における同種の個体密度を上回ることはなかった．また，調査期間中，ウルマーシマトビケラ *Hydropsyche orientalis* は掘削区においてほとんど捕獲されなかった．これらの結果は，河道掘削された地点における土砂除去面積だけでなく，完成した河道形状による流速の低下がトビケラ群集の回復過程に影響を及ぼしたことを示唆する．掘削区においては，最終調査日の約２週間後に発生した大規模洪水によりトビケラ類の調査を継続できなかったが，トビケラ群集の回復過程に及ぼした河道掘削の影響はこの洪水によって相殺されたと考えられる．