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Effects of Debris Flows on In-channel Sediment Deposits and Habitat Structures in Steep Headwater Streams

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Synopsis

Disturbance plays key roles maintaining species diversity and ecosystem function in wide range of ecosystems. We examined relationships between debris flow history and stream habitat structure (in-channel sediment deposits, abundance of streambed elements, occurrence of different types of microhabitats) using 42 headwater streams with different histories of debris flows in a managed forest watershed, Totsukawa, Nara. In-channel sediment deposit was highly correlated with channel slope and valley width, and related little to debris flow history. Number of large woody pieces and woody debris dams were more in streams with older occurrence of debris flow. Erosive microhabitats such as bedrock, splash zone, moss mat were common in all streams, while depositional microhabitats such as mud and leaf pack occurred only in streams with old (>30 yrs) debris flow, and sand was absent in streams with very old (>50 yrs) debris flow. These results indicate that stream habitat diversity is dynamically maintained in a repeated manner through debris flow history.

Keywords: headwater streams, debris flow, sediment deposit, habitat structures, microhabitats, aquatic invertebrates

1. Introduction

Disturbance in an ecological context can be defined as a discrete event that disrupts individuals and populations of organisms (Pickett and White, 1985). It has been recognized that disturbance plays key roles determining species richness, biomass and production of organisms in wide range of ecosystems (Connell, 1978; Sousa, 1984; Pickett and White, 1985). In rivers and streams, disturbance represented by flood is usually accompanied with processes of erosion and deposition (Bilby et al., 2003). Species richness of aquatic organism is assumed to be the maximum in streams with moderate frequency and intensity of flooding (Connell, 1978; Townsend et al., 1997). Therefore, nature restoration managements of streams and rivers should incorporate disturbance in their concepts and practices. In order to realize such management, however, knowledge on the magnitude and frequency of disturbance that maintains structure and function of ecosystems is inevitable.

High-intensity disturbance, such as severe floods, has a major role modifying physical structure of stream ecosystems (Bilby et al., 2003). Diverse habitats in stream ecosystems are often related to streambed topography, which is generated by dynamics of sediments controlled by high-intensity disturbance. Fast flowing riffles and slow flowing pools are fundamental habitat components (Kani, 1944; Frissell et al., 1986), and sorted accumulations of various substrate materials (e.g., stones, sand, mud, aquatic plants, detritus) within a pool and riffle provide different microhabitats for benthic organisms. Decrease of sediment supply and flood frequency due to large dam construction often results in loss of habitats and species richness at downstream reaches (Hatano et al., 2005). Due to stochastic occurrence, few studies have been done to elucidate roles of high-intensity disturbance on stream ecosystems.

Debris flows that scour channel and riparian zones are high-intensity disturbance in steep headwater streams. Mass movements that occur as landslides on hillslopes are typically transformed as debris flows in channels (Benda and Cundy, 1990). Natural occurrence of debris flow is considered to be rare (recurrence interval: 100–1000 yrs). However, debris flow regimes can be modified by human activities. For example, landslides and debris flows occur more frequently in managed forest areas (Sidle and Ochiai, 2006); probability of landslides increase 3 to 15 yrs after clear cutting associated with decreased rooting strength prior to sufficient vegetation recovery (Sidle, 1992). Inversely, their occurrence would be reduced by constructions of sabo-dams and slope stabilization works.

Debris flow can affect physical structure of streams by scouring and redistributing in-channel sediment deposits. May and Gresswell (2003) reported that debris flows flush out sediment and woody pieces and increased channel with exposed bedrock in steep headwater streams of Coast Range of Oregon. Removal of sediment and woody pieces in channel can create channel dominated by fast-flow habitats and coarse substrates (Bilby et al., 2003). In contrast, sediment and woody pieces are considered to increase at debris terminal and downstream sections.

We have been studying relationships between forest clear cuttings and debris flow occurrences, and impacts of debris flows on stream ecosystems using headwater catchments with different histories of clear cuttings and debris flows. We previously revealed that probability of debris flow occurrence increased 1 to 15 years after clear cutting, with a peak during 5 to 10 years, and invertebrate community differed between streams with recent debris flows (<20 yrs) and streams with old debris flow (>30 yrs). Invertebrate taxa typical of fast flow conditions (lotic taxa) were more abundant in streams with recent debris flow, while invertebrate taxa typical of slow flow conditions (lentic taxa) were more abundant in streams with old debris flow.

In this study we examined relationships between debris flow history and in-channel habitat structure of headwater streams. The habitat structure was evaluated by three properties of different hierarchical levels; reach-scale sediment deposits, pool-riffle-scale habitat properties, and composition of microhabitat types. A total of 15 microhabitat types are distinguished here as a unit area with relatively homogeneous in substrate type and size (e.g., bedrock, cobbles, sand, detritus), to which organisms respond at an individual level.

2. Site descriptions and Methods

2.1 Study site

The study was mainly conducted in a small mountain watershed (8.5 km^2, 34˚04′E, 135˚35′N, 860–1370 m asl.) in the central Kii-peninsula (Totsukawa village, Nara prefecture; Fig. 1). The area is upstream of Kanno River, within Kumano river basin (2360 km^2). Surface geology in the area consists of alternating beds of sandstone and shale or claystone. Hillslopes are steep (>40˚) with thin surface soils (<1 m in depth). Annual precipitation in the area ranged from 2122 to 3508 mm from 1998 to 2002.

Clear cuttings and plantation of commercial trees, mainly Japanese cedar (*Cryptomeria japonica* D. Don), have been conducted since 1912 in the area. Tree-cutting is usually operated in early summer, followed by harvesting in autumn and planting in the next spring. After 30 yrs of plantation, the stands were thinned for about 25% of trees. Because these practices were operated within small catchments (operation blocks consisted of a single or a few headwater catchments), the 8.5 km^2 study watershed contained stand ages ranging from 1- to 91-yrs-old. These catchments differed in histories of debris flow occurrence. Occurrence of debris flow determined from aerial photographs taken in 1964, 1967, 1971, 1976, 1984, 1989, 1994, 1998, and 2003 revealed that at least one debris flow occurred in 67 out of 89 headwater catchments after 1964. Among all the debris flows detected, duration between the year of clear-cutting and the year of debris flow detection was 0–4 years for 23%, 5–9 years for 39%, 10–14 years for 27%, 15–19 years for 8% and 20–30 years for 4%.

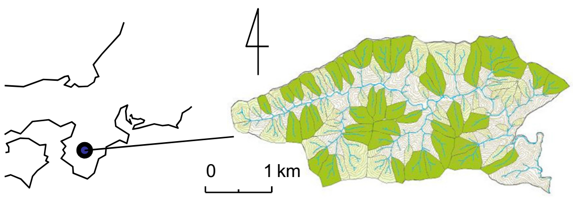

Fig. 1 A map of the study site, the upstream area of Kanno-gawa river. Surveys on sediment deposits and habitat properties were conducted in streams of colored catchments.

Table 1 Stand age and debris flow history (detected by aerial photos) of 42 catchments surveyed in this study.

Stand age	The year of the last debris flow							
	2003	1998	1994	1989	1984	1971	<1964 or no occurrence	Total
0-9 yrs							5	5
10-19 yrs	1	2	4				1	8
20-29 yrs		1		7	3			11
30-39 yrs				3	5	2	1	11
40-49 yrs				1		3		4
>90 yrs							2	2
Undisturbed forest							1	1
Total	1	3	4	11	8	5	10	42

2.2 Surveys on sediment deposits and habitat properties

Surveys on in-channel sediment deposits and streambed elements were conducted on July and August 2006, when discharge was relatively low and stable. Forty-one streams in the watershed and one stream in an undisturbed forest catchment located 2.7 km west from the managed watershed were used (Table 1). Watershed area of studied catchments ranged from 3.8 ha to 22.5 ha (mean = 4.8). In each stream, a 150–300 m channel reach was surveyed. Among surveyed reaches mean channel slope ranged from 20% to 48% (mean = 34%), and mean valley floor width ranged from 2.6 m to 10.9 m (mean = 4.8 m). Percent length of the reach covered by sediment deposits was measured by classifying channel into either of bedrock or sediment. The criterion classifying bedrock and sediment was whether sediment deposits covered the whole width of in-stream or bank. To know the percent contribution of woody debris on whole sediment deposits in the reaches, sediment deposits with logs or braches at their front was recorded.

Number of large woody debris (LWD), woody debris dams, pools and steps in channel was counted as streambed elements in each reach. We counted the number of woody pieces exceeding 10 cm in diameter and 1 m in length, which were attached on streambed. Woody debris dams were accumulations of branches and/or long needles of Japanese cedar, which exceed 50 cm in accumulation width. Pools are locally slow flow areas (more than 1 m in length and 20 cm in depth) associated with bedrocks, sediment deposits, logs or organic dams. Steps are vertical fall that exceed 50 cm in height.

2.3 Surveys on microhabitat composition

Ten catchments with different stand ages and debris flow histories were selected from the 42 catchments for a

Table 2 Stand age and debris flow history of 10 catchments, in which a microhabitat survey was conducted. Number and types of reaches used for the survey are also shown.

Stand age of catchments	The year of the last debris flow	Watershed area (ha)	Number of reaches			
			Whole bedrock	Bedrock dominated	Sediment dominated	Whole sediment
1	<1964	4.7		2	2	
2	<1964	6.6	1	3		
16	1998	6.2	2	1		
18	1994	5.9		1	2	1
19	1994	12.9		1	3	
27	1989	6.5	3	3		
31	1989	3.8	1	3		
42	1971	9.0	1	4		
91	<1964	5.1	1	3		
Undisturbed forest	<1964	7.7		1	3	

microhabitat survey (Table 2). We used channel reach between two steps (3–10 m in channel length) as a unit of microhabitat survey in this study. In each stream, 3 to 6 replicate reaches were randomly selected. Reaches were classified according to amount of sediment deposits in channel; whole bedrock reaches (percentage of channel length covered by sediment deposits: <5%), bedrock dominated reaches (5–50%), sediment dominated reaches (50–95%) and whole sediment reaches (>95%). Types of reaches differed among the 10 streams according to the amount of sediment deposits in each stream (Table 2).

A total of 15 types of microhabitats were distinguished based on substrates and flow patterns (Table 3). Among the microhabitat types, bedrock, splash zone, moss mat and submerged root are microhabitats typical in erosive environment. In contrast, sand, mud and deposited leaves are microhabitats typical in depositional environment. The survey unit (i.e., reach) was divided into different habitats (i.e., step, rapid, riffle, pool, isolated pool, side channel) and into mid-channel and channel periphery, and presence/absence of 15 types of microhabitats were recorded for each compartment.

3. Results

3.1 Sediment deposits and habitat properties

Percent of channel length covered by sediment deposits ranged from 6% to 100% among 42 streams. Percent of sediment deposits in channel was less related to either forest age or debris flow history (Fig. 2). Contribution of woody debris on sediment deposits in channel ranged from 0% to 59% with mean of 16% among the streams. In each stream, most sediment deposits were observed at locations where valley floor were relatively wide and/or channel gradient were relatively low.

Among the three parameters (watershed area, mean channel slope, mean valley floor width), mean valley floor width was highly correlated with percent length of sediment deposits in channel ($r = 0.53$, $p < 0.001$). This correlation was weakened ($r = 0.39$, $p < 0.01$) when the widest stream, which was 100% in sediment coverage, was excluded. Percent length of sediment deposits in channel did not correlated with neither of watershed area ($r = 0.03$) nor mean channel slope ($r = 0.01$).

Abundance of LWD was relatively high in streams with young (< 10 yrs) and very old stand (> 90 yrs) compared to streams with middle-aged forest, and was constantly low in streams of 20- to 35-yrs-old stand (Fig. 3). In terms of debris flow history, LWD was most abundant in streams with very old occurrence of debris flow (< 1964). Similarly, abundance of woody debris dams was low in streams with 10- to 30-yrs-old forest compared to young (< 10 yrs) and matured (> 40 yrs) forest. Woody debris dams was also higher in streams with older occurrence of debris flow (Fig. 3). Abundance of pools was variable in streams with 30-yrs-old and younger forest, and was constantly low in stream with 35-yrs-old and older forest. Abundance of pools and steps did not show clear relationships with history of debris flow (Fig. 3).

Table 3 Definitions of 15 types of microhabitats. Each microhabitat exceeds 400 cm^2 in patch area.

Type	Explanations
Bedrock	Bedrock without any other substrates and covers
Splash zone	Wetted bedrock or large stone with almost no water depth
Moss mat	Patches of moss cover
Submerged root	Tree root in water
Woody debris	Wood > 3 cm in diameter
Leaf packs	Tightly compacted leaf accumulations
Unembedded stones	Inorganic particles > 64 mm in size less embedded (< half of the particle) with fine sediments
Embedded stones	Inorganic particles > 64 mm in size much embedded (> half of the particle) with fine sediments
Pebbles	Accumulations of inorganic particles 2-64 mm in diameter
Hypohreic	Accumulations of pebbles with > 10 cm in depth
Sand	Inorganic particles < 2 mm in diameter
Mud	Accumulations of organic particles < 1 mm in diameter
Deposited leaves	Loosely compacted leaf accumulations
Submerged plants	Terrestrial vascular plants in water
Emergent plants	Aquatic plants

3.2 Microhabitat composition

Totally 42 reaches were surveyed for the occurrence

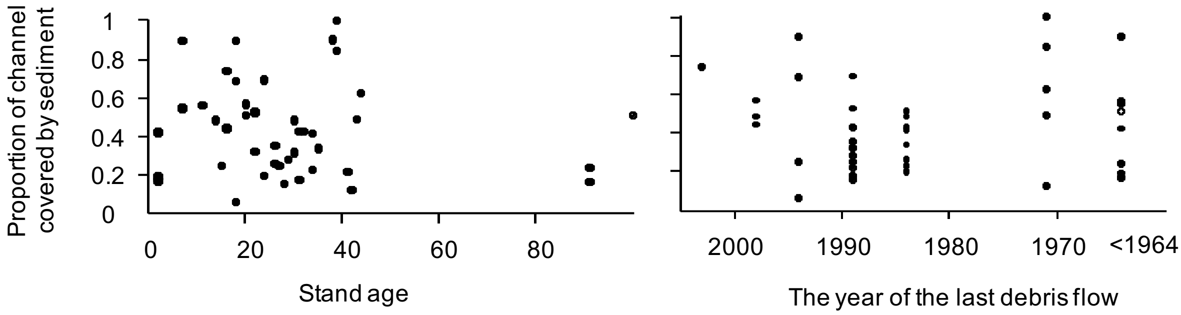

Fig. 2 Proportion of channel length covered by sediment deposits plotted against stand age (on the left) and the year of the last debris flow (on the right). Filled circle: managed forest catchments, open circle: undisturbed forest.

of microhabitats in 10 streams. Bedrock, splash zone and moss mat, which are microhabitats typical of erosive environment, and unembedded stones occurred in most of the reaches at either mid-channel or periphery of channel. Similarly, large woody pieces, embedded stones, pebbles, hypohreic occurred in 60–90% of the reaches. Sand, mud and bottom leaves, which are microhabitats typical of depositional environment, and submerged root were less common among the reaches (10–40% of the reaches). Submerged plants and emergent plants occurred only 3–6% of the reaches. All microhabitats excluding bedrock and unembedded stones tended to occurred more frequently at periphery than at mid-channel. This was most pronounced for moss mat, whose occurrence at mid-channel was almost half of the occurrence at periphery. In each reach, microhabitats distributed unevenly among habitats (Fig. 4). Step and rapid occurred in most of the reaches (83–90% of the reaches), while riffle and pool occurred less frequently (48–74%), and isolated pool and side channel occurred in very limited reaches (5–7%). Bedrock, splash zone and moss mat occurred more frequently in step and rapid, while many other microhabitat types occurred more frequently in riffle and pool.

Forty-two reaches were classified into 9 whole bedrock reaches, 22 bedrock dominated reaches, 10 sediment dominated reaches, and one whole sediment reach. In whole bedrock reaches, bedrock, splash-zone and moss mat always occurred, while mud and bottom leaves were completely absent (Fig. 5). In bedrock dominated reaches and sediment dominated reaches, many microhabitats including large woody pieces, packed leaves, unembedded stones, embedded stones, hypohreic, pebbles, mud, and deposited leaves occurred more frequently compared to whole bedrock reaches. Although some microhabitats occurred slightly more frequently in sediment dominated reaches than bedrock dominated reaches, no large difference in the occurrence of microhabitats between these two reaches. Only 9 microhabitats occurred in a single whole sediment reach.

Occurrence of microhabitats varied among the 10 streams, and the occurrence of some depositional microhabitats including sand, mud and deposited leaves was limited to streams of particular stand ages (Fig. 6). Log, mud and deposited leaves tended to occur more frequently in streams of very young (1- and 2-yrs-old) and matured forest (> 42-yrs-old), which experienced debris flow more than 30 yrs ago, compared to streams of middle-aged forest, which experienced debris flow within 20 yrs (Fig. 6). Many streams of middle-aged forest lacked mud and deposited leaves. On the other hand, sand occurred most of the streams of middle-aged forest, while this microhabitat was absent in many streams of very young and matured forest (Fig. 6). Three out of four streams with no occurrence of debris flow since 1964 lacked sand microhabitat. Occurrence of other microhabitats including moss mat, submerged root, hypohreic, embedded stones, pebbles, submerged plants and emergent plants also varied among streams, but their occurrence was unrelated to stand age and debris flow history of the streams.

4. Discussion

4.1 Sediment deposits and streambed elements related to debris flow history

It has been widely recognized that debris flows scour the channels through which they travel, and sediment storage in the channel increase during the interval between debris flows (Gomi et al., 2002; May and Gresswell, 2003; Bunn and Montgomery, 2004). However, our results suggest that debris flow history was minor as a factor of the variations of sediment storage at least among our studied streams (Fig. 2).

There were dissimilarities in characteristics of channels and sediment deposits between streams of this study and the previous studies (e.g., May and Gresswell, 2003), which may be responsible for the difference in results. Our streams were relatively smaller in watershed area (mean ± 1SD: 8.3 ± 3.5 ha) and relatively higher in channel gradient (34 ± 6%) compared to the streams of previous studies [in May and Gresswell (2003), watershed area: 11.4 ± 3.8 ha, mean channel slope: 30 ± 5%]. Mean valley floor width of our streams was relatively larger and variable (4.7 ± 1.6 m) comparing to the other studies [in May and Gresswell (2003), 4.1 ± 0.7 m]. In addition, large woody debris (LWD) contributed less on sediment storage in channel in our streams (16% on average) than in other studies [> 70% in May and Gresswell (2003)]. There were multiple sediment storage sites without LWD in the studied streams, including locally gentle and wide channel sites that dissipate stream power. Sediment is likely to be stored at these sites even during debris flow occurrence as well as during subsequent sediment movement from hillslopes to channels. Thus, in our studied streams, sediment storage was more likely to be determined by geomorphic characteristics of channels rather than processes occurring during the intervals between debris flows (e.g., accumulations of large woody pieces). Sediment storage was highly correlated with mean valley floor width in this study.

Abundance of LWD in the channel did not show a simple linear relationship to debris flow history in this study (Fig. 3). LWD was abundant in many streams with the oldest occurrence of debris flow (< 1964).

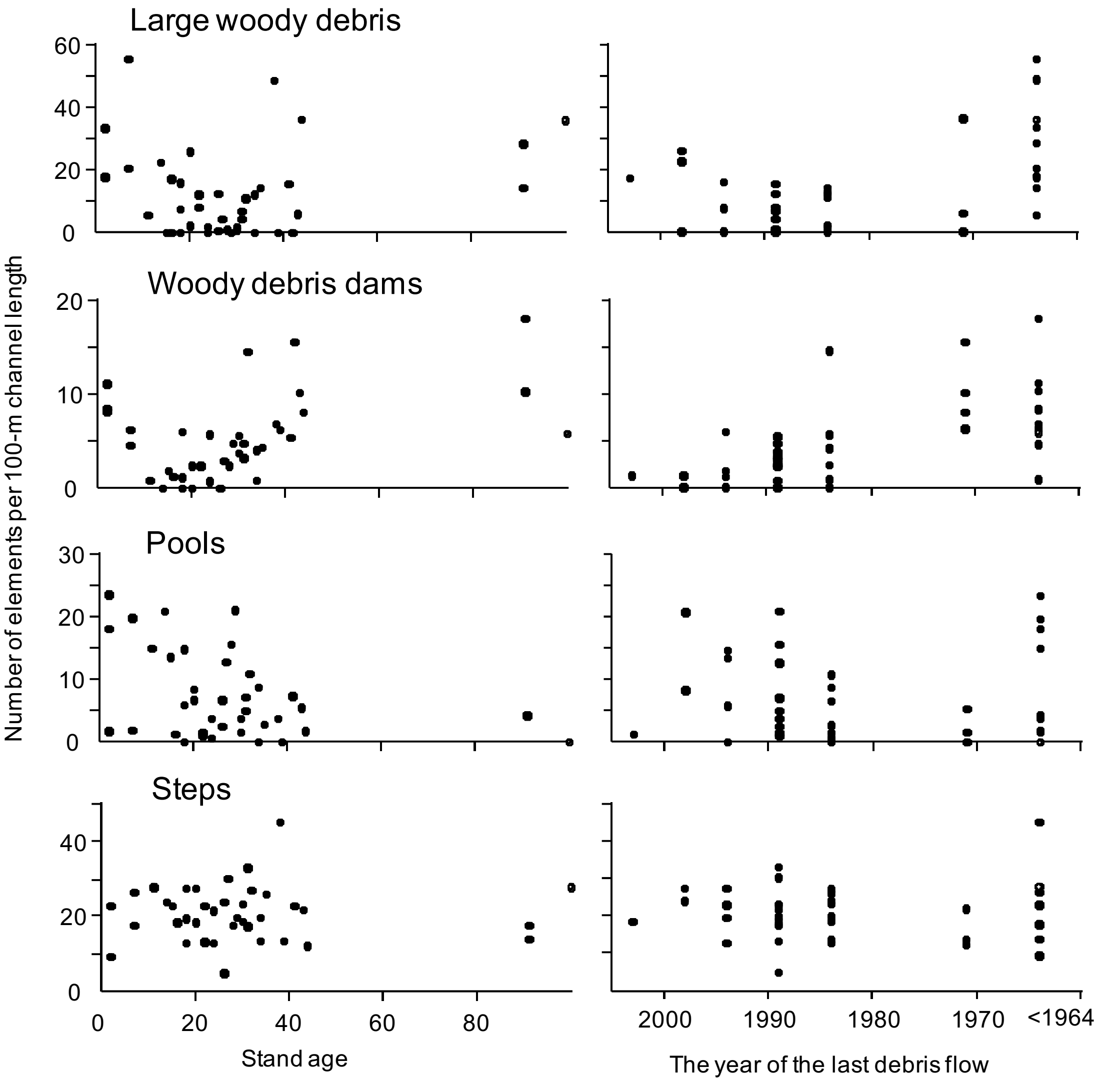

Fig. 3 Number of large woody debris, woody debris dams, pools and steps per 100-m channel length plotted against stand age (on the left) and the year of the last debris flow (on the right). Filled circle: managed forest catchments, open circle: undisturbed forest catchment.

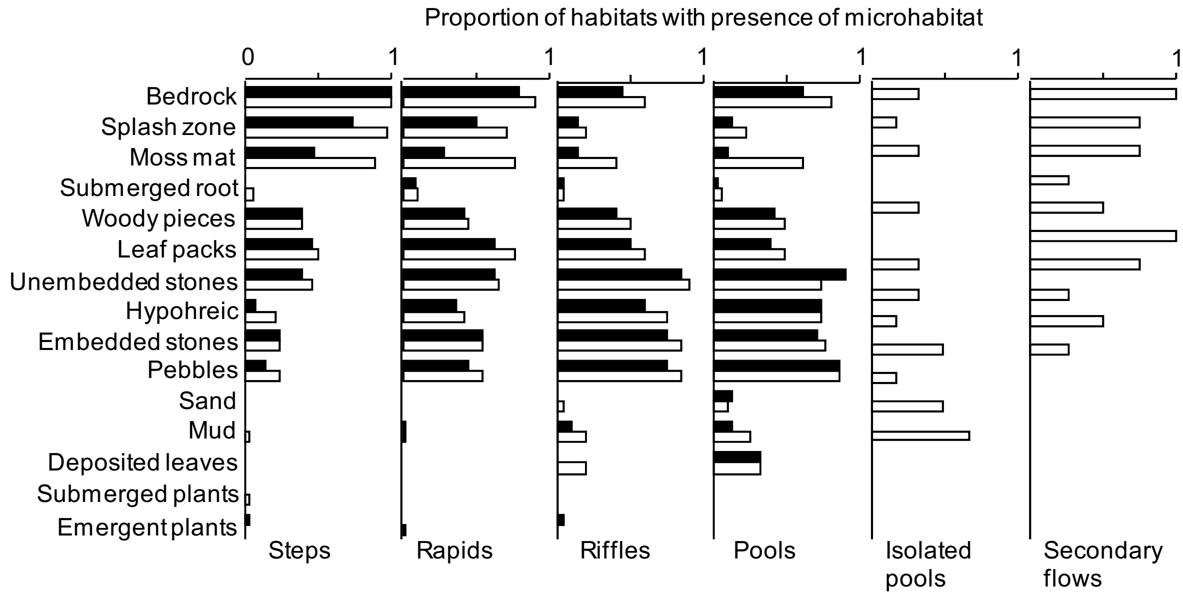

Fig. 4 Occurrence of 15 types of microhabitats in different habitats throughout the all reaches. Dark bars denotes occurrence at mid-channel and open bars denote occurrence at periphery.

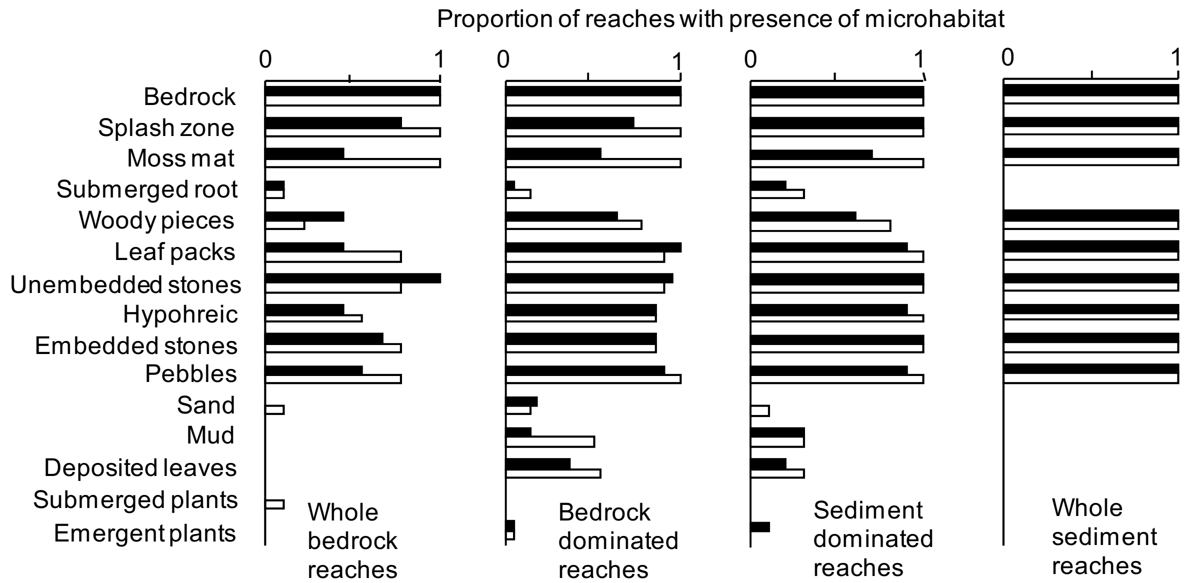

Fig. 5 Occurrence of 15 types of microhabitats in different types of reaches. Dark bars denotes occurrence at mid-channel and open bars denote occurrence at periphery.

These streams were also draining young or matured forest. In such study sites, substantial LWD might be supplied into channels as logging slash and unmerchantable timber during clear cutting and during thinning, which is usually operated 30 yrs after clear cutting. These pulse wood inputs by the management practices would be largely responsible for the higher abundance of LWD in streams of young and mature forest. Abundance of LWD tended to decrease gradually with stand age up to 30 yrs. Occurrence of debris flow may be one of the process that decrease LWD in the channel (May and Gresswell, 2003; Gomi et al., 2003), though streams with the most recent debris flow was not the lowest in abundance of LWD. There might be a time lag between clear cutting and the LWD supply from hillslope through debris flow. In addition, LWD may be flushed out by high flow events without debris flow when LWD are decomposed and weakened in the channel.

Abundance of woody debris dams in the channel seems to be largely affected by debris flow history. Woody debris dams are considered to be structured by

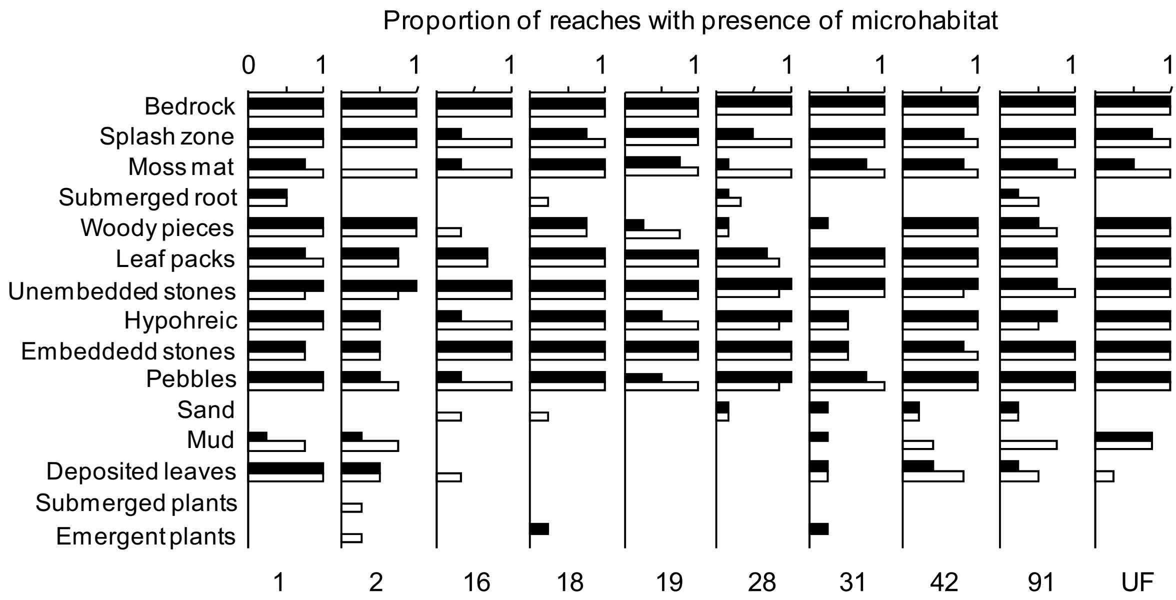

Fig. 6 Occurrence of 15 types of microhabitats in 10 catchments with different stand ages and debris flow histories. Numbers at the bottom are stand age of catchments. See Table 2 for debris flow history of each catchment. Dark bars denotes occurrence at mid-channel and open bars denote occurrence at periphery. UF: undisturbed forest catchment

many woody pieces that have been transported and accumulated during high flow periods. Since branches and long needles of Japanese cedar are easily supplied from riparian vegetations compared to LWD, woody debris dams are potentially generated in the channel at any ages of forest. During debris flow occurrence, a dam-like structure would be collapsed by unwinding and breaking of woody pieces. Although branches and needles may be supplied to the channel from hillslopes during debris flow occurrence, a dam-like structure is unlikely to be generated during debris flow. Almost no woody debris dams were found in streams with the most recent debris flows (Fig. 3).

Abundance of woody debris dams in the channel would largely affect habitat structure of aquatic invertebrates. Number of pools and steps was less related to debris flow history. This is partly because that portion of pools and steps in the channel is formed by bedrock and sediment deposits, whose dominance in the channel was unrelated by debris flow history (Fig. 2). Although pools have important roles generating depositional environment for aquatic organisms in the channel and enhancing retention of materials, not all pools are equal in their function. Pools created by woody debris dams seem to be more effectively reduce flow velocity in the channel compared to pools created by bedrocks and sediment. In addition, a dam-like structure also contributes reducing flow velocity even during high flows. Thus, debris flow history can affect aquatic environment indirectly through affecting abundance of woody debris dams that create depositional and retentive environment in the channel.

4.2 Features of microhabitat structures related to debris flow history

This study was the first trial to evaluate microhabitat structure in headwater streams in relation to habitat scale variations in stream with different debris flow histories. Surveys on 42 reaches revealed some microhabitat features of headwater streams. Among the 15 types of microhabitats, bedrock, splash zone and moss mat, all of which are typical in erosive environment, were commonly observed for all the reaches. The commonness of erosive microhabitats is reasonable in these steep gradient channels. Unembedded stones, hypohreic, embedded stones and pebbles, which are related to sediment deposits, were also frequently observed. In contrast, sand, mud and deposited leaves, which are typical in depositional environment, occurred in limited reaches. Thus, the occurrence of these microhabitats would be one of the keys determining microhabitat diversity in these headwater streams. Occurrence of submerged root, submerged plants and emergent plants was much limited among the reaches. Vascular plants are less likely to colonize inside and nearside streams in these headwater areas due to dominance of bedrock in the channel and/or a disturbance prone environment.

Comparison of microhabitat occurrences among reaches with different sediment storages shows some relationships between sediment storage in the channel and microhabitat diversity. In whole bedrock reaches occurrence of many microhabitats was less than the other reaches, and some microhabitats were completely absent. Meanwhile, there was no large difference in microhabitat occurrences between bedrock dominated and sediment dominated reaches. These results suggest that microhabitat diversity of headwater streams is largely dependent on the presence or absence of sediment deposits in the channel, while the amount of sediment deposits has relatively small effect on the diversity.

Occurrence of some microhabitats was related to debris flow history of the streams. First, mud and deposited leaves occurred less or completely absent in streams with recent debris flows. Few occurrences of these microhabitats agree with less abundance of depositional environment generated by woody debris dams in these streams. Thus, debris flows are likely to influence the microhabitat diversity indirectly through reducing abundance of woody debris dams in the channel. Second, sand microhabitat was absent in streams with the oldest occurrence of debris flow. Since sand is easily flushed away during high flow events, supply from hillslopes seems to be important to maintain this substrates in the channel. Places of landslide that trigger debris flows and banks eroded by debris flows seem to be major sources of sand supply in these headwater streams. The sand microhabitat was absent in streams with the oldest debris flow occurrence, probably because banks and hillslopes were stable, and thus, amount of sources of sand supply was low in these catchments.

4.3 Linkages between debris flow history and stream ecosystems through habitat structures

We previously revealed that invertebrate taxa typical of fast flow conditions (lotic taxa) were more abundant in streams with recent debris flow, while invertebrate taxa typical of slow flow conditions (lentic taxa) were more abundant in streams with old debris flow (Disaster Prevention Research Institute Annual Meeting 2005). This pattern of invertebrate community agrees with findings of this study that depositional environment and related microhabitats were less in stream with recent debris flow. Thus, it is suggested that modification of in-channel hydraulic environment and microhabitat structures is one of the important mechanisms of debris flow influences on invertebrate community in these headwater streams.

Our results suggest that microhabitat diversity of headwater streams decrease temporally after debris flow occurrence through loss of mud and deposited leaves, while no occurrence of debris flow for a long period also reduce microhabitat diversity through loss of sand microhabitat in the channel. Since, many invertebrates are specialized to certain substrates and microhabitats for completing their life stages, debris flow can potentially affect invertebrate diversity through changing microhabitat diversity.

5. Conclusions

In this study, we examined relationships between debris flow history and in-channel habitat structure using 42 steep headwater streams with different debris flow histories. We revealed that in-channel sediment storage related little to debris flow history, while abundance of woody debris dams and occurrence of some microhabitats typical of depositional environment strongly related to debris flow history. Results of this and previous study suggest that debris flow affect invertebrate community through modifying in-channel hydraulic conditions and microhabitat structure in these headwater streams. Debris flows can potentially affect invertebrate diversity through determining microhabitat diversity. Further studies that link microhabitat structure and invertebrate community are needed to fully understand roles of debris flow on invertebrate diversity in headwater streams.

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源頭渓流において土石流が河道内土砂と生息場構造に及ぼす影響

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要旨

奈良県十津川村の人工林施業域において、土石流発生履歴の異なる42の源頭渓流を対象に、河道内土砂量、ハビタット要素の多さ、ミクロハビタット構造を調査した。土石流発生履歴と河道内土砂の関係は見られなかったが、土石流によって倒木、落葉枝ダムや堆積卓越型ミクロハビタットが減少することを明らかにした。底生動物群集を規定するミクロハビタットの多様性は土石流発生の履歴とともに変動することを示した。

キーワード：源頭渓流、土石流、河道内土砂、生息場構造、ミクロハビタット、底生動物