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Ecohydrological Roles of Debris-Flow and Flood in Stream Ecosystems and Challenges for Their Restoration

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Abstract

Historical evidences in sediment strata indicate frequent events of flood and/or debris-flow in Japan. It means that most of the species in biological communities have experienced such hazards repeatedly and ecosystems have been maintained in relation to the catastrophic physical disturbance at the hazards. In this paper, possible roles of flood and debris-flow in an ecological context, such as habitat creation and maintenance by sedimentation processes, reset of biological succession by disturbance, seal with toxic material accumulated under undisturbed conditions, etc. are reviewed based on some empirical data obtained in river and coastal ecosystems. Considering with the state of human life owing to products of ecosystems, it could be concluded that we had better associate with natural hazards not by prevention oriented but by control or use oriented manner. This way of thinking is coherent with the concept of "risk management" which emphasize as well as predicting natural disasters efficiently enough for taking refuge before and after the crises.

Keywords: debris-flow, microhabitat structure, benthos community, natural hazard, ecosystem management.

1. Introduction

Disturbance is one of the key words in ecology as a driving force of biological community structure and material cycles in a wide range of ecosystems including forest, marine, floodplain and stream ecosystems (Connel, 1978; Sousa, 1984). In case of comparatively dry land ecosystems, disturbance by wildfire has been considered as an inevitable and indispensable factor for maintain species diversity in the ecosystem (Trabaud and Lepart, 1980). Even in humid forests in Japan, some pioneer plant species appear just after the fire and become dominant in the early stage of succession, and this results in the highest plant species diversity in 1-2 years after the fire (Tsuda et al. 1988). Such a terrestrial ecosystem requiring fire for its maintenance has been so called "fire prone ecosystem" (Iizumi, 1991).

Importance of disturbance has been focused on in marine and freshwater ecosystems after Connel (1978) presenting the "intermediate disturbance hypothesis". It predicts that disturbance of intermediate intensity will maximize species diversity by reducing density of dominant species and create "open" habitat for more fugitive species in inter-specific competition. Although the role of disturbance in community has been implicated by this conventional theory (e.g., Leibold and Miller, 2004), such species interactions may be effective only in a community under equilibrium condition. Since the communities of streams and rivers in monsoon Asia are often under non-equilibrium conditions because of frequent sediment movement by flood, the intermediate disturbance theory might be inapplicable. Another role of disturbance, instead, such as promoting habitat alteration and rearrangement can be more important in the ecosystems (Takemon, 1997).

In this situation, "habitat structure" will be a key concept bridging between disturbance regimes and ecological outcome such as community structure and patterns of material cycling (Fig.1). Geomorphology and hydrology are two major fields for physical mechanisms of habitat structure (Maddock, 1999). In addition, basin ecosystems of most countries have been altered artificially for the purpose of resource utilization and/or flood control. And thus, disturbance regimes and resultant habitat structure can be interpreted as a function of human manipulation, too (Fig.1). This aspect will be particularly important when we make impact assessment for any artificial alteration of natural systems, such as sediment control works, reservoir dams and barrages, which will change ecohydrological properties of the system.

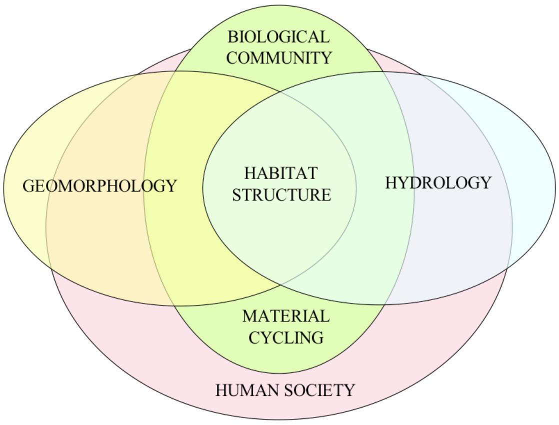

Fig. 1 Habitat structure as an interface between physical disturbance regimes and ecological outcome under influences of human society.

In this paper, an example for relations of benthos community to habitat structure is shown based on results of comparative study between streams of old natural forest and those of deforested basin (Forest Function Research Committee, 2000). And then, roles of the physical disturbance by flood and/or debris-flow are discussed from the aspects of habitat creation and maintenance through sedimentation processes.

2. Impacts of Debris Flow After Deforestation On Stream Benthos Communities

The debris flow in the first and second order streams is often initiated by logging of the forest (Gomi et al., 2006). A field study was conducted in three first order streams in the Yunishi Gawa, a tributary of the Kinu Gawa basin in Tochigi Prefecture in 1998-1999 (Table 1)(Forest Function Research Committee, 2000).

Table 1. Profiles of the three streams in the Yunishi Gawa in Tochigi Prefecture, in eastern Japan.

Stream name	Stream order	Altitude (m)	Basin area (ha)	Natural forest area (%)	Age after logging (year)
Akashita Zawa	1st	800	35	99.7	45〜65
Menbori Zawa	1st	700	52	32.9	12〜13
Naga Sawa	1st	1000	44	10.5	13〜14

One of the three streams, Akashita Zawa, was surrounded by an old natural forest of more than 45 years old (Old forest). Menbori Zawa was a partially logged stream with riparian forest left along the channel (Riparian forest). And Naga Sawa was a stream in a thoroughly logged forest without riparian forest (Clear-cut forest).

The streambed of “Old forest” was composed of distinctive step-pool units without sediment accumulation, whereas, those of “Riparian forest” and “Clear-cut forest” received a big amount of sediment derived from debris flow occurred after logging. Most of pools in these streams were very shallow filled with sand and stones. Microhabitat structure and benthos community structure were compared among these streams.

2.1 Difference in habitat structure

Stream microhabitats in the study area were classified into 15 categories according to Takemon (1997). The microhabitat appearance at each location in the channel and habitat unit was recorded using a matrix sheet shown in Table 2. The microhabitat categories are arranged in order from erosive to depositional ones under low flow conditions. A total of five stream units (unit: a set of riffle-pool) were surveyed in each stream.

Microhabitat diversity was estimated as a total number of microhabitat categories found in a stream unit. Average values of the diversity were distinctively different among streams of “Old forest”, “Riparian forest” and “Clear-cut forest” (Fig.2). Microhabitat diversity was the lowest in “Old forest” because of the erosive conditions resulted in absence of sandy substrates and less packed stones (stones of partially buried conditions). On the contrary, both “Riparian forest” and “Clear-cut forest” had abundant sediment forming sandy and muddy substrates in pools in addition to erosive microhabitats in steps and rapids.

Table 2. A matrix sheet used for stream microhabitat survey. The numbers show example data taken in a stream unit.

Location in channel	Location in habitat unit	erosive ←							Microhabitat categories							→ depositional
		base rock	hygropetric zone	moss mats	root mats	drift wood	litter pack of dam type	unpacked stones	packed stone	hyporheic zone	gravel bed	sand bed	mud bed	litter pack of deposit type	emergent vegetation	vegetation cover
Central	step	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0
	rapid or riffle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	glide	0	0	0	0	1	1	0	1	1	1	1	0	1	0	0
	pool	1	0	1	0	1	0	0	1	1	0	1	1	1	0	0
peripheral	step	1	1	0	0	1	1	0	0	0	0	0	0	0	0	1
	rapid or riffle	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1
	glide	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1
	pool	1	0	1	1	1	0	0	1	1	0	1	1	1	0	1
	bankside pool	0	0	1	1	1	0	0	0	1	0	1	1	1	0	1

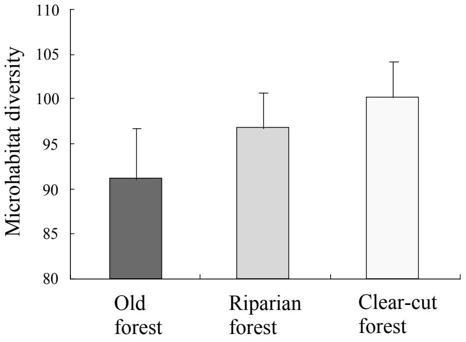

Fig. 2 Difference in microhabitat diversity (a total number of microhabitat types found in a stream unit) among the three streams in the Yunishi Gawa. Each mean value was significantly different at 5% level (n=5, t-test).

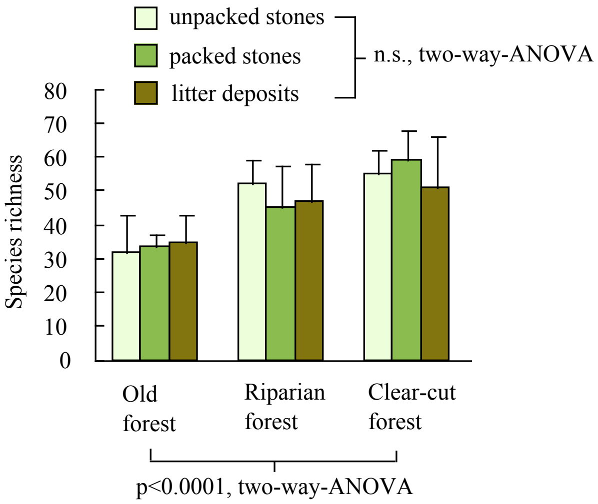

Fig. 3 Difference in species richness (a total number of species collected in an area of 625 cm^2) of benthos communities among the three streams in the Yunishi Gawa. Replications were 4 times for each sampling

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2.2 Difference in benthos communities

Benthos samples were collected quantitatively using the Surber net at three microhabitats. Four replications were made in each stream. Benthos samples preserved in 10% formalin were sorted in the laboratory and identified into species or genus level.

A total of 28,836 animals belonging to 160 taxa were identified in the total of 36 samples from the three streams. Species richness defined by the total number of taxa was the highest in “Clear-cut forest”, the lowest in “Old forest” and intermediate in “Riparian forest” (Fig.3). This inclination was common among the three microhabitats. Only 5 species were restricted to “Old forest”, whereas as much as 55 species were found only in “Riparian forest” and “Clear-cut forest”.

The higher species richness in “Clear-cut forest” was originated by more number of burrowing species that inhabit sandy and muddy microhabitats and by grazer species living on periphyton, such as diatoms and green algae. The increase of burrowing animals occurred also in "Riparian forest" and thus it was likely to relate to the sediment increase derived from logging in the basin, whereas the increase of grazers occurred only in "Clear-cut forest", which indicated that they benefited from higher primary production caused by increased light intensity after clear-cut of the forest.

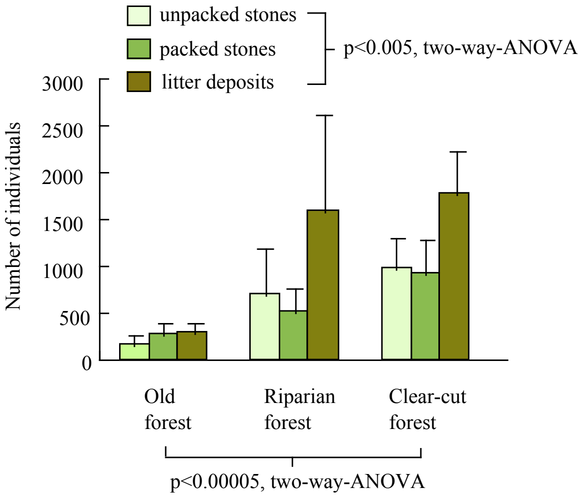

Fig. 4 Difference in abundance of benthic animals (a total number of individuals collected in an area of 625 cm^2) among the three streams in the Yunishi Gawa. Replications were 4 times for each sampling.

The total abundance of benthic animals showed a similar pattern to the species richness. (Fig.4). This result indicates the benthos abundance is also influenced not only by productivity but also by the habitat structure created by the sediment supply through debris flow.

2.3 Ecological roles of debris flow

The example in this paper indicates that disturbance creates spatial and temporal heterogeneity that is important for maintaining species diversity. The results also indicate that benthos communities become richer though increase in habitat heterogeneity.

The roles of disturbance for habitat formation may be more important under non-equilibrium conditions, but even in equilibrium conditions it may still interact with biological processes in natural communities (Sousa, 1985; Lake, 1990). Therefore, disturbance as an agent of creating and conditioning environmental patches for settlement by populations should be given more emphasis in community ecology and in biodiversity management.

Temporal changes in microhabitat diversity and biological communities after a debris flow may be an important future subject. Since the severe physical disturbance is expected to make damages for populations of vulnerable species, the biodiversity seems to decrease drastically just after the debris flow. As the age of "Clear-cut forest" and "Riparian forest" was 12-13 and 13-14 years old, respectively, the increase of biodiversity should occur during several to a dozen of years after the debris flow.

When we consider biodiversity in a reach scale, it may be maximized by the sediment supply like the case of the Yunishi Gawa. When we look at in a regional scale, however, the existence of minor 5 species restricted to "Old forest" must be important. They might be fond of the erosive environment of old natural forest. Therefore, in order to maximize total biodiversity, patchwork patterns of basins different in forest ages and sediment load will be ideal.

2.4 Perspectives for natural hazard management

In the later half of the last Century, many of Japanese rivers lost sediment dynamism by sediment control works, dam construction and channel works in order to prevent disasters. Natural hazards such as flood, earthquake, tsunami and typhoon, however, cannot be prevented when their scale exceeds our ability to manipulate. In this sense, "disaster prevention" aiming at extinction of disasters is unrealistic. This is why "disaster reduction" has been required as a risk management strategy (Kawata, 2005). Now, it is clear that the "disaster reduction" philosophy is coherent with the requirement of natural disturbance for the purpose of ecosystem conservation and restoration. From both aspects of disaster reduction and environmental restoration, it is fruitful to develop methodology for "natural hazard management" allowing the sediment dynamism within a range of disaster reduction.

3. Conclusions

Member of benthos communities in Japanese mountain streams benefit from debris flow that reforms their microhabitats into heterogeneous structure. Although previous methods for nature conservation and restoration have been limited to peacetime manipulation, such ecohydrological roles of natural hazard should be reflected in the ecosystem management. The "natural hazard management" for “disaster reduction” will provide a favorable chance to keep and/or restore ecosystems in healthy conditions.

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