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Structure and Function of Riparian Zone and Implications for Japanese River Management

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Abstract

This paper describes the ecological structure and function of riparaian zone which vary with spatial scale. The riparian zone consists of valley floor landform and riparian vegetation. The functions discussed are attenuation of sunlight energy, input of leaves and needles, contribution of woody debris to streams, and retention of flowing material out of transport. These primary functions directly or indirectly influence water and sediment qualities of streams, bars and floodplains. Shading provided by tree crowns over the stream strongly influences water temperature and primary production in lotic ecosystems. Litter falling into streams is a critical food resource for stream organisms, especially in forested headwater streams. Coarse woody debris supplied from hillslopes and floodplains create storage sites for organic and inorganic matters and enhance habitat diversity for aquatic biota. Moreover, stems and roots of riparian vegetation comb inorganic and organic matter transported from upstream, increasing the soil nutrients of floodplain deposits. Variation in valley floor width plays an important role in retaining materials transported in stream water by increasing hydraulic and geomorphic complexity. Generally, these functions diminish with an increase in watershed area although some functions are kept in floodplains of large rivers. The main reason for this longitudinal variation is due to changes in the relative size of riparian trees and the stream channel. The new river management policy should emphasize the ecological functions of the riparian zone. Finally, the author proposes river restoration planning by preserving or creating landscape elements based on the concepts of sustaining physical and ecological linkages.

Key Words: *Riparian zone, Riparian structure, Ecological function, Flood control, River environment.*

Introduction

The landscape of Japan displays very steep and undulating terrains. Annual precipitation is considerable, ranging from 1000 to 3000 mm. Heavy rains and subsequent floods are generally caused by typhoons in summer. These natural conditions strongly influence Japanese river management policy, which has historically focused on flood control. This policy, however, changed dramatically after the 1890s. Prior

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to the 1890s, rivers were used as routes for material transportation. Therefore, management policy was focused on flood control without deteriorating ordinary needs such as water utilization. Dutch scientists and technicians who were served as advisors to the Meiji government in the 1870s stressed the importance of dealing with a river as a continuum from upstream to downstream, combining water utilization with flood control. The Dutch low-water river techniques, however, came under increasing criticism after repeated floods during the 1880s in Japan. Simultaneously, river transportation gave way to railways. This allowed river management policy to shift primarily to flood prevention works, such as levee constructions in the 1890s. This policy has succeeded and, thus, most Japanese rivers were embanked or dammed with concrete structures.

Since the 1970s, public opinion with respect to river management has greatly shifted from flood prevention to environmental preservation, partially in relation to pollution in many industrialized regions. Presently, preservation of the natural environment has become a key issue for the management of Japanese rivers. For example, the Hokkaido Prefectural Government proposed green belts called "riparian corridors" along rivers (Hokkaido Prefecture, 1992). The ideas presented in this proposal are innovative but too idealistic to apply to the real world, because of the lack of knowledge on structure and function of riparian zone. Many studies on the riparian zone were recently presented in the United States (Swanson et al., 1982; Gregory et al., 1991), where scientists drew public attention to the ecological functions of riparian vegetation.

First, I present the important characteristics of riparian zone with special reference to its structure and function, based on research conducted in Hokkaido, northern Japan and in the Pacific Northwest of the United States. Other studies are cited from published references to reinforce or to complete the discussion. Finally, a new perspective on Japanese river management policy based on current scientific understanding is proposed. The rivers discussed in this paper are montane creeks with steep gradient and meandering streams with gentle gradient. The riparian forests are composed of large coniferous trees such as Douglas-fir (*Pseudotsuga menziesii*) and Western Hemlock (*Tsuga heterophylla*) in Oregon, and deciduous trees such as elm (*Ulmus* spp.) and willow (*Salix* spp.) species in Hokkaido.

General Concept and Scale

The riparian zone is structured by river and hillslope geomorphologies providing a template and by vegetation on that template (Fig. 1). Hillside footslopes adjacent to the valley floor were included as a component in the riparian zone, because mass movement such as landslides on lowerslopes may directly influence channel morphology (Swanson and James, 1975), and forests establishing on these lowerslopes may strongly influence ecological functions of stream and riparian systems.

Valley floor landforms consist of terraces, alluvial fan, floodplains, bars and streams. Riparian forests are able to establish on all these geomorphic surfaces except streams. The forests on hillslopes and the valley floor have several ecological functions such as attenuation of sunlight energy, input of leaves and needles, contribution of woody debris, and retention of flowing materials out of transport, which results in the alteration of water and soil qualities of streams, bars and floodplains (Fig. 1). Shading provided by tree crowns hanging over the stream strongly influences water temperature and primary production in lotic ecosystems. Leaves and twigs falling into streams are critical food resources especially in forested headwater streams where light is limited. Coarse woody debris (CWD) pieces from adjacent slopes and floodplains function as obstructions in streams, providing storage sites for sediment and organic matter and enhancing habitat diversity for aquatic organisms. Moreover, stems and roots of riparian vegetation comb inorganic and organic matter transported from upstream when the floodplain is inundated, which increases the soil nutrients of floodplain deposits. The interaction between floodplains and streams through ground-water drainage systems is not well understood, but recent studies indicate the importance of floodplain vegetation in improving the nutrient quality of flowing water. In addition to riparian vegetation, hillslope and valley floor landforms directly influence energy or material flows from adjacent terrestrial and upstream ecosystems.

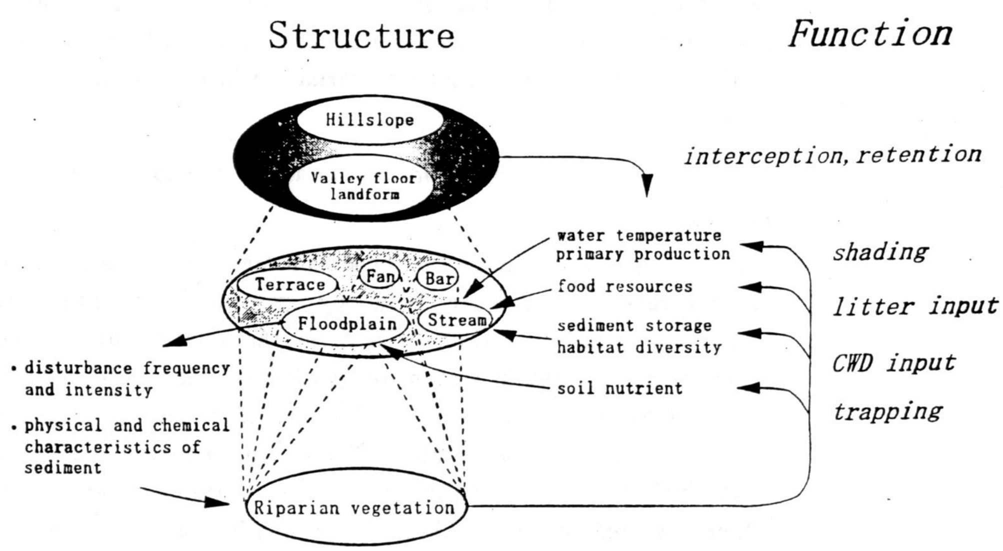

Fig. 1. Conceptual model of structure and function of riparian zone.

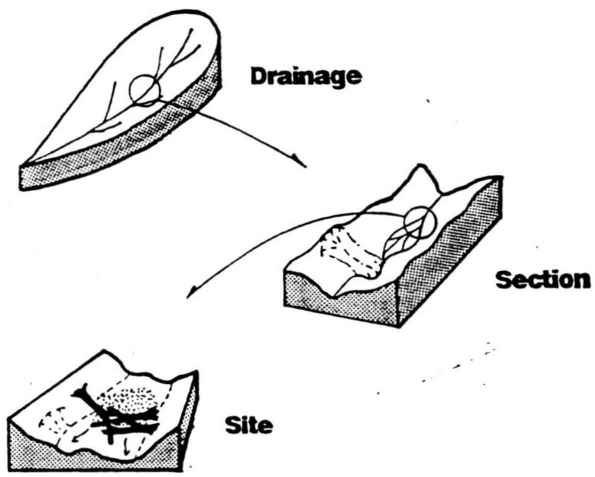

Fig. 2. Hierarchical organization of riparian zone.

They play an important role in intercepting, retaining and releasing incoming energy and materials, thereby influencing the allocation of nutritional resources or habitats for most aquatic organisms.

The structure and function of the riparian zone vary with spatial and temporal scale. The dynamics of riparian structure and resultant changes in function are excluded from the discussion because their systems are extremely complex and very few speculative studies are available. However, spatial scale is considered in this paper, representing three hierarchical systems shown in Fig. 2, and discussed in terms of their structural and functional variations in each scale.

Structure and Function of Riparian Zone

Local scale

Interception of sunlight by floodplain tree crowns is a widely known function of riparian zone. The pioneer studies by Brown and his colleagues (Brown, 1969; Brown and Krygier, 1967 and 1970) focused on the relationship between the percentage of shading and increase in stream temperature. These studies were carried out in headwater streams in coniferous forests composed mainly of Douglas-fir in the Pacific Northwest of the United States. The stream surface is heavily shaded by tree crowns, which inhibits sunlight penetration and decreases solar energy to 1/35 of full intensity. Other research was carried out in a gentle gradient stream, the Horonai River in Tomakomai Experimental Forest, Japan. Results showed that the daily maximum and total solar radiation were reduced to approximately 1/4 and 1/7 of full sun by crown-

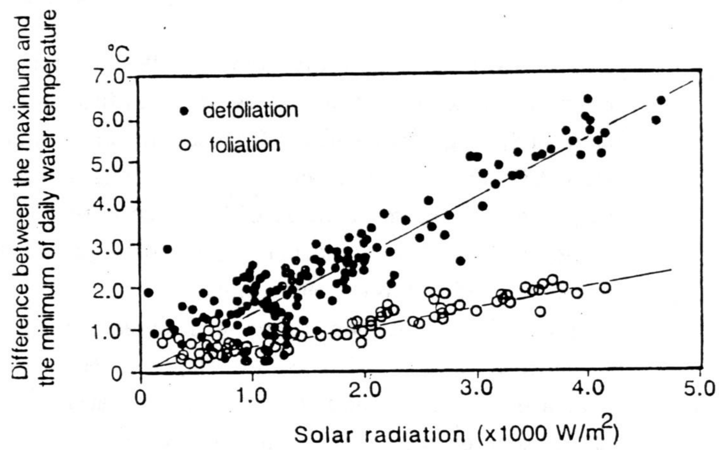

Fig. 3. Relationship between solar radiation and differences in the daily water temperatures during defoliation and foliation periods (from Nakamura and Dokai, 1989).

shading in summer, respectively (Nakamura and Dokai, 1989). This stream is almost completely covered by deciduous broad-leaved trees. Obviously, there are considerable fluctuations in water temperature between defoliation and foliation periods in deciduous broad-leaved forests (Fig. 3). This seasonal variation in water temperature has a great impact on the life of aquatic organisms.

Litter supply from riparian vegetation to stream was mainly investigated in the United States. Fisher and Likens (1973) discussed leaf fall from the energy budget point of view in the headwater streams of hardwood forests. They clarified the importance of allochthonous detritus in aquatic ecosystems, indicating that over 99% of organic matter was supplied by the surrounding forests. Gosz et al. (1972) reported that the volume of leaf fall to headwater streams is not significantly different from leaf fall to the forest floor. Litter-fall to stream measured in the Tomakomai Experimental Forest was about 2.5 tons/ha, which is slightly lower than the volume of leaf fall on the forest floor (unpublished information). Gregory et al. (1991) stressed the important role of herbaceous and shrub litter input to streams by indicating that herbaceous plants account for up to 75% of the foliar production in herb and shrub-dominated riparian zones in northwest United States.

Tree-fall from banks or hillslopes provides CWD pieces to streams. The tree-fall is initiated by mortality, windthrow, landslides originating from an upslope initiation site, streamside slides and bank erosion. Observation of CWD structures in headwater streams suggests alternative developmental sequences and associated geomorphic responses (Nakamura and Swanson, 1993). When trees fall from hillslopes or banks, slope or bank surfaces may be disturbed by uprooting and subsequent failures. In many cases, stream flow diverted by CWD obstruction scours the foot of a hillslope or stream banks, and this may result in additional tree fall and slope or bank failures. Some long, large-diameter CWD pieces capture smaller ones, which occasionally develop into CWD-jams. Organic matter and sediment delivered from upstream are collected within and upstream of these CWD structures. Consequently, the streambed widens in response to a combination of erosional processes triggered by diverted flow and deposition behind CWD obstructions.

Interactions between forest and stream through CWD can be also observed in meandering streams with gentle slopes. Pools and structures that provide hiding cover are important components of habitat structure for aquatic organisms, especially fish (Bisson et al., 1982). Coarse woody debris in the Sarufutsu River, northern Hokkaido, Japan, significantly contributes to the complexity of stream morphology (Fig. 4), through the formation of pool and cover structures (Abe and Nakamura, submitted). Approximately 40% of pools and 50% of habitat cover structures were created by CWD fragments, respectively. Thicker, longer pieces oriented perpendicular to the channel were effective in forming pools and cover. More than 50% of

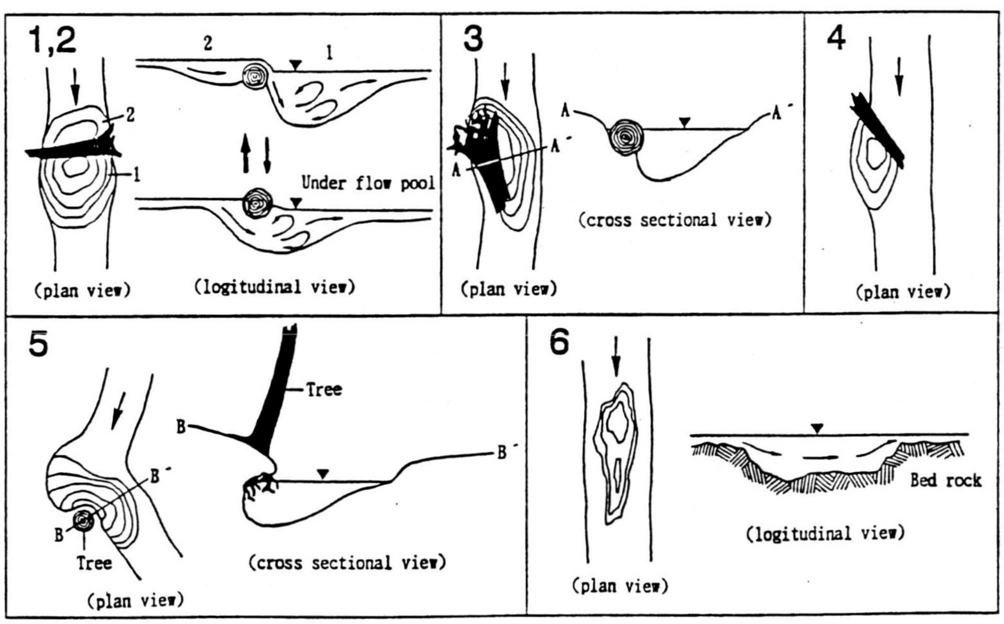

Fig. 4. Schematic illustration of pool types in the Ninosawa Creek. Arrows and dashed lines indicate directions of stream flow and contour lines of water depth, respectively. Pool types are classified after Bisson *et al.* (1982). 1: plunge pool, 2: dammed pool, 3: lateral scour pool associated with obstructions, 4: backwater pool, 5: lateral scour pool associated with channel bend, 6: trench pool (from Abe and Nakamura, submitted).

pool formation associated with CWD was reported in the headwater streams covered by conifers in the western United States (Lisle and Kelsey, 1982; Keller et al., 1985; Harmon et al., 1986).

Forests on floodplains in large, broad rivers enhance riverbed roughness when floodplains are inundated. Flow depth over the floodplains is shallower than on the riverbed due to higher geomorphic surfaces. Higher roughness and lower flow depth on floodplains in turn result in diminished stream power to transport particulate organic matter and fine sediment delivered from upstream. Thus, materials are deposited. Trees on floodplains adapt to these conditions by sprouting adventitious roots from buried stems. Dendro-geomorphological research in a broad river in southern Hokkaido, the Saru River (drainage area: 1345 km^2), indicates that silt and sand sediment was deposited about 20-50 cm in depth by a single flood. Johnson et al. (1976) investigated the relative age of floodplain surface and organic matter content in the floodplain soil of the Missouri River in the United States. I see a correlation between the two factors from their published data (Fig. 5). The older the floodplain, the higher the organic content, although there is a substantial variation in this trend. Both chronic litter-supply from trees on floodplains and repeated trapping of organic matter out of transport may be responsible for the increase in organic matter in the soil with age.

Section scale

The geomorphology of headwater streams is not only formed by fluvial processes but also influenced by mass movements initiated on hillslopes. Further, alluvial fans,

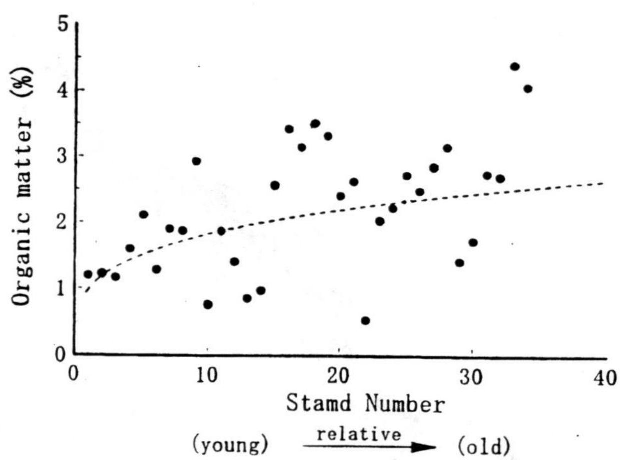

Fig. 5. Organic matter content in the upper 60 cm of soil in 34 stands along the gradient of relative stand age, studied in the Missouri River in North Dakota (made from the data published by Johnson *et al.* (1976)).

which develop at the junctions with tributaries, vary the channel geomorphology of the main stream. An example of the headwater stream is illustrated in Fig. 6. The constrained reach in the downstream is built by expansion of alluvial fans developing from both sides of the main stream. Another constrained reach found in the mid-stream is formed by the deep-seated, slow-moving landslide entering from the south. This landslide contributes to the development of the upstream unconstrained reach. Cross-sectional profiles across the constrained and unconstrained reaches are compared in Fig. 7. Generally, terraces and floodplains develop in unconstrained reaches with a relatively wide valley floor, and stream channels are allowed to migrate laterally in a "braided pattern". Each of the secondary channels carries a small amount of water. On the other hand, a single channel carrying a large volume of water develop in narrow reaches constrained by hillside slopes. Accordingly, riparian forests established in unconstrained reaches are different in age (Nakamura, 1986a), and complex in structure and species composition (Okamura and Nakamura, 1989), whereas trees such as willow and alder rarely grow along the stream channel in constrained reaches.

Canopy opening is greater in the unconstrained valley floor because of broad channel width and frequent streamside disturbances. Obviously, solar radiation entering the unconstrained valley floor is very high, and therefore water temperature and

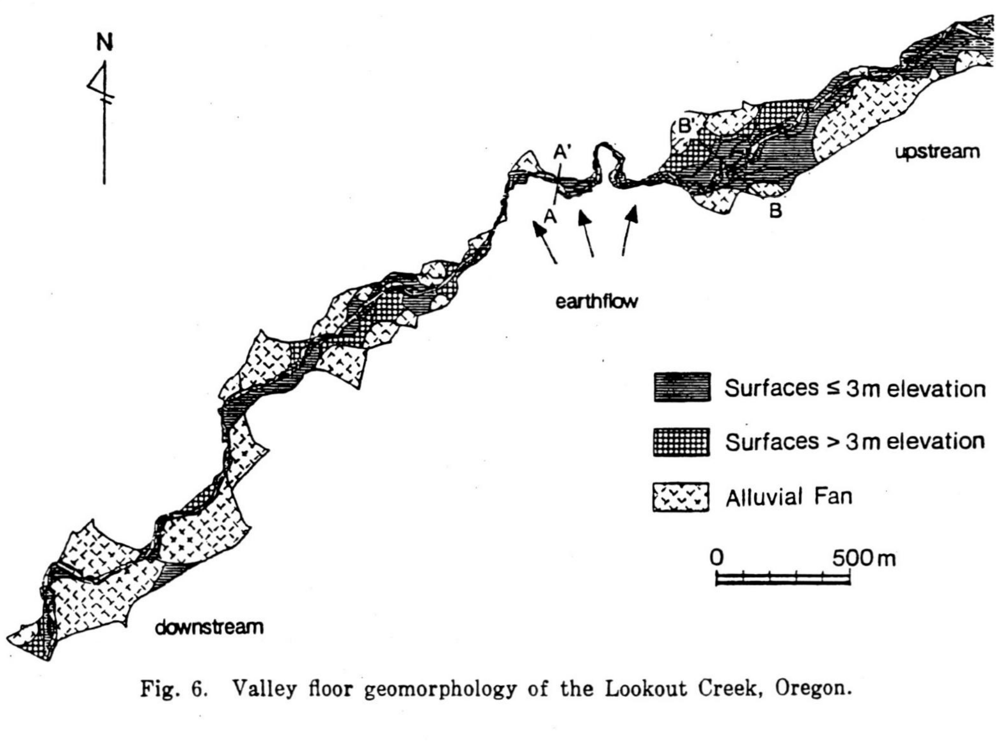

Fig. 6. Valley floor geomorphology of the Lookout Creek, Oregon.

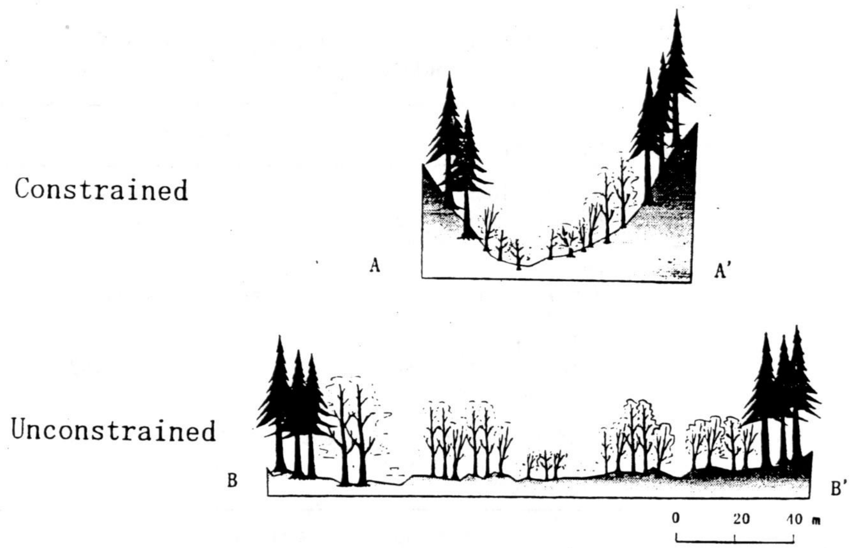

Fig. 7. Cross-sectional profiles of the constrained and unconstrained reaches. Locations are shown in Fig. 6.

primary production in the streams increase. Low velocity and shallow depth of secondary channels contribute to this increase. From an ecological point of view, these wide valley floors in headwater streams are similar to the braided channels found in alluvial fans in high-order basins.

Decrease in stream power in a wide, unconstrained reach provides storage sites for sediment (Nakamura, 1986b), fine organic litter (Lamberti et al., 1989), and CWD (Nakamura and Swanson, 1994). Distribution of floodplain sediment in relation to valley floor width was examined along the Saru River. The volume of floodplain sediment correlated with valley floor width (Nakamura, 1990; Madej, 1984). Large storage sites were predominantly observed in wide sections of a riverbed, where older sediment is mainly located.

The influence of channel geomorphology on retention of leaves was investigated in Lookout Creek, a coniferous headwater stream in Oregon by Lamberti et al. (1989). They released exotic Ginkgo (*Ginkgo biloba*) leaves into the channel as a tracer to measure travel distance. Valley floor landforms were classified as four reaches with reference to broadness of the valley floor, vegetation, and presence or absence of multiple channels (Table 1). They found that retention of leaves was about five times higher in unconstrained reaches in both old-growth and second-growth riparian zones. They concluded that unconstrained reaches, having geomorphically complex channels, diverse riparian vegetation, woody debris, and heterogeneous stream hydraulics, play

Table 1. Geomorphic characteristics and leaf retention in four study reaches of Lookout Creek, Oregon (from Lamberti, G. A. et al. (1989)).

Parameter	C	D	E	G
Valley Floor	Constrained	Unconstrained	Constrained	Unconstrained
Riparian vegetation	Old-Growth	Old-Growth	2nd-Growth	2nd-Growth
Multiple channels	Absent	Present	Absent	Present
Canopy	Closed	Partly Open	Open	Partly Open
Woody debris	Sparse	Abundant	None	Abundant
Valley Floor Index [1]	1.3	6.9	2.8	6.0
Total Length (m) [2]	415	1198	391	663
No. Channel Unit	17	52	13	34
Leaf retention Coefficient	0.008	0.031	0.008	0.045
Average Leaf Travel Distance (m)	132	33	125	22

1 Valley floor width (m) / Active channel width (m)
2 Cumul[illegible] [illegible]gth of all channels

important roles in retaining particulate matter and dissolved nutrients in stream ecosystems. In terms of interaction between CWD obstruction and transported leaves, Speaker et al. (1984) found that CWD pieces and sticks greatly enhance the potential for leaf retention in streams.

Unconstrained reaches experience frequent disturbances of the valley floor forests by lateral shift of channel location, and CWD fragments often enter multiple channels. Riparian trees also impede the transport of large CWD fragments in flows, trapping fluvially transported pieces on the floodplains and at the entrances of secondary channels. Floodplains at the outsides of bends act as large "trash racks", trapping CWD from flood flows. Therefore, the number and volume of CWD pieces vary along the channel with respect to channel width, sinuosity, and occurrence of storage sites. The distribution of CWD was examined in Lookout Creek in Oregon with special reference to channel geomorphology (Nakamura and Swanson, 1994). Peaks of CWD abundance approximately correspond to areas with relatively high concentrations of storage sites, which were located generally in wide and/or sinuous reaches. Stream channels were classified into six reach types based on channel width, sinuosity, and presence of multiple channels (Fig. 8). The multiple channels greatly contribute to the abundance of CWD, especially to trapping fluvially transported pieces, because the discharge divided into multiple channels is not adequate to carry most CWD pieces. Large CWD jams commonly dominate entrances of multiple channels where channel divergence causes stream discharge and width to shrink abruptly.

Pools to serve as a habitat for aquatic organism vary with the abundance of CWD pieces. The percentage of CWD pieces influencing pool formation was compared

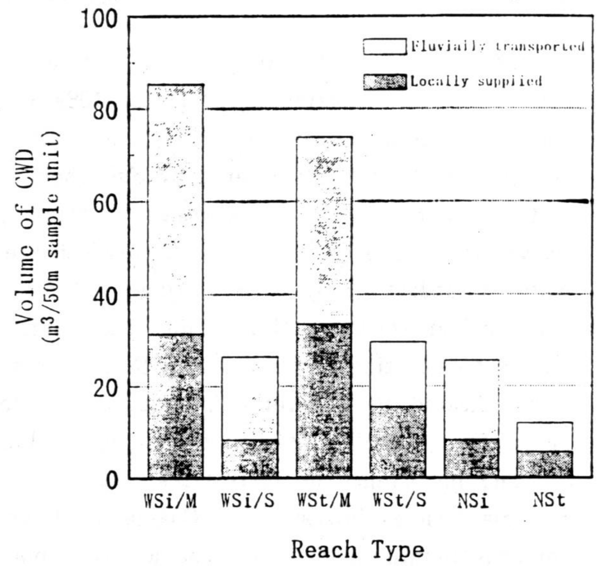

Fig. 8. Volume of CWD compared among the six reach types. WSi/M: wide and sinuous reaches with multiple channels, WSi/S: wide and sinuous reaches with single channel, WSt/M: wide and straight reaches with multiple channels, WSt/S: wide and straight reaches with single channel, NSi: narrow and sinuous reaches, NSt: narrow and straight reaches. Details are explained in Nakamura and Swanson (1944).

among the six reach types (Fig. 8). About 17% of CWD pieces in wide, sinuous reaches with multiple channels affected pool formation; this percentage is two to five times greater than for the other types (Nakamura and Swanson, 1994). These reaches had the greatest lateral (wide valley floor) and vertical (relatively fine sediment) channel mobility, and therefore, the greatest opportunity for pool formation by CWD. The contribution of small pieces to pool formation was pronounced in wide, sinuous reaches, where 64% of pool-forming CWD pieces were shorter than 5.0 m in length. In other reach types, the percentage of pool-forming pieces shorter than 5.0 m ranged from 0 to 43%.

Drainage scale

River Continuum Concept (RCC) by Vannote et al. (1980) provides a framework for integrating physical and biological elements along a river system. The relationship between riparian vegetation and stream ecosystems vary from headwater to broader rivers. The main reason for this longitudinal variation in interaction is due to changes in the relative size of riparian trees and stream channels. Thus, previous studies of the interactions have focused on headwater stream where the relative size of riparian tree to channel width is large, resulting in significant interactions.

The effect of riparian trees on stream temperature decreases with increasing channel width. Nakamura and Dokai (1989) examined the relationship between riparian tree heights, crown diameter, and channel width in the broad-leaved forest streams, predominantly covered by *Salix* spp., *Alnus hirsuta*, *Populus maximowiczii* and *Ulmus davidiana* var. *japonica*. Assuming the tree height of developed riparian forests is 25 m, streams having 15 m-width are presumably suffered high increase in water temperature by tree cutting, and streams having 30 m-width are suffered medium increase by cutting. They also estimated the expected temperature increase due to tree-cutting in the Horonai River. The simulation based on heat-budget analysis indicated that water temperature may increase approximately 4°C as a daily maximum by cutting riparian trees over a 4-km stretch of the river.

The importance of terrestrially derived (allocththonous) detritus to stream ecosystems declines downstream. Coarse woody debris pieces in high-order streams cannot develop into predominant obstructions, functioning as retainers for trapping organic matter out of transport. Rather, they lie on floodplain deposits in broader streams. A decrease in the number of instream obstructions results in reduced retention capacity of flowing organic matter in the channel, and thus, diminishes the available food to stream biota. Aquatic primary production (autotrophy), in turn, plays an important role in ecosystem dynamics in broader rivers (Minshall et al., 1985).

Studies in the Lookout Creek drainage basin show that the effects of CWD on channel morphology and storage of organic matter and sediment vary with stream size (Nakamura and Swanson, 1993). Comparison of average channel width with respect to watershed area reveals that the width of channels increases with an increase in watershed area (Fig. 9). This correlation suggests that channel morphology is determined primarily by basin hydrology. However, channel widths with CWD obstructions are about 1.5 to 2.3 times wider than channels without CWD obstruction. In low-order streams, CWD pieces delivered by blowdown, or transported from upper reaches become obstructions anchored to banks or hillslopes, which create vertical and horizontal variations in channel structure. Stream channels greater than fifth-order are relatively free to migrate laterally. Large CWD-jam structures are rare in these channels because of the channel's high capacity to float CWD before it aggregates. The predominant effect of CWD on material storage in broader rivers is deflection of the thalweg, which results in lateral scouring and deposition of the riverbed.

Most functions of the riparian zone addressed in this paper seem to diminish with an increase in watershed area. However, there are many functions that are not discussed here and not thoroughly elucidated by previous studies. Sedell and Froggatt (1984) described the changes from the pristine to the present streamside forest, channel geomorphology, and role of downed trees in a large river (9th-order) in Oregon.

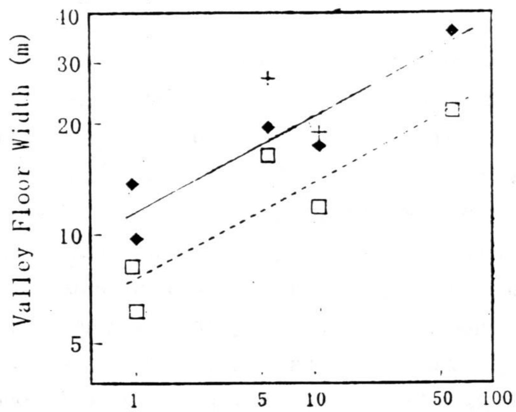

Fig. 9. Regressions of average channel widths of reaches with no CWD (broken line), CWD obstruction (solid line). Legends; □: no CWD, ◆: CWD obstruction, +: CWD-jam. (redrawn adding CWD-jam data to Nakamura and Swanson (1993)).

Development of multiple channels in the pristine state of the large river provided numerous efficient storage and retention sites for particulates in sloughs and snag-obstructed channels. They emphasized that the ecological role of wood in large rivers will never be completely understood because large rivers have been channelized and streamflow modified by dams etc., and snags and riparian vegetation have been removed. Swanson and Sparks (1990) compared large, floodplain rivers with small, mountain streams and indicated that forest-stream interactions are played out predominantly in the flooded floodplain environment of the large, lowland river and in the channel of the steep, mountain river. The role of riparian vegetation with respect to the nutrient cycle has been examined in small forested streams (Triska et al., 1989; Wallis et al., 1981; Wondzell, 1994). However, this role in large rivers through ground water has not yet been studied except Stanford and Ward (1988), and is therefore not well understood.

Management Implications

I propose a new perspective for Japanese river management based on structure and function of the riparian zone addressed previously. Japanese rivers have been altered to prevent flood and debris flow disasters. Land use development in Japan is very intensive given its limited land resources. The more land is developed, the greater the peak discharge of rivers and higher the value of buildings to protect, resulting in increased prevention structures. This suggests the need to discuss river management policy in terms of land use in river basins.

The concept of landscape structure is illustrated in Fig. 10. Presumably, a fragment of landscape is preserved as a conservation area. The outside area is referred to as the "external environment" or "matrix". The conservation area is composed of patch mosaics and each patch has a different function or multiple functions. This organization is referred to as "internal structure". In this system, functions are systematically coordinated and components are holistically organized. In other words, all components must have a specific function or multiple functions for the system to work effectively. This assumption is supported by the studies on habitat structure. For example, the habitat of sika deer (*Cervus nippon yesoensis*) consists mainly of areas of foraging, moving, covering and surviving in winter (Sakamoto et al., 1995). Thus, removal of one habitat element by land development will accelerate extinction of sika deer. Maintenance of the external environment is also essential in order for the conservation area to function effectively. Changes in matrix areas greatly influence the quality of the conservation area. For example, removal of riparian trees which reduce solar radiation may cause complete extinction of a specific species favoring cool temperature, even if habitat cover, pools and foods are provided (Barton et al., 1985).

Sharp increases in peak flow discharge following intensive development in basins is counterbalanced by constructing high levees or excavating the riverbed in Japan. With respect to flood-control, a basin can be zoned according to function into water retention, inundation, and conveyance areas. As an example, the Toikanbetsu River basin (276 km^2), northern Hokkaido, was zoned into these three areas and their functional changes between pre-settlement (1900) and the present (1980) were compared

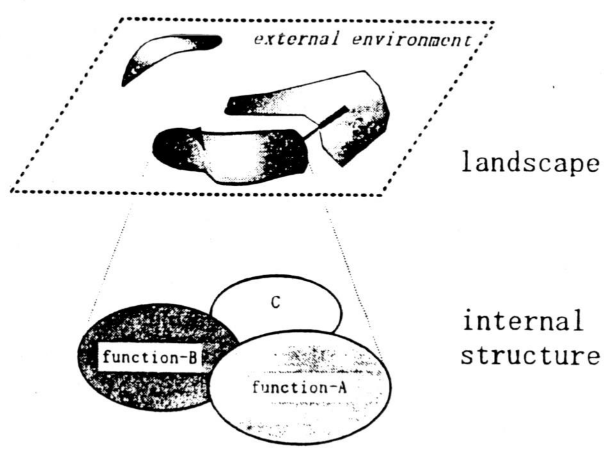

Fig. 10. The concept of structure and function of landscape elements.

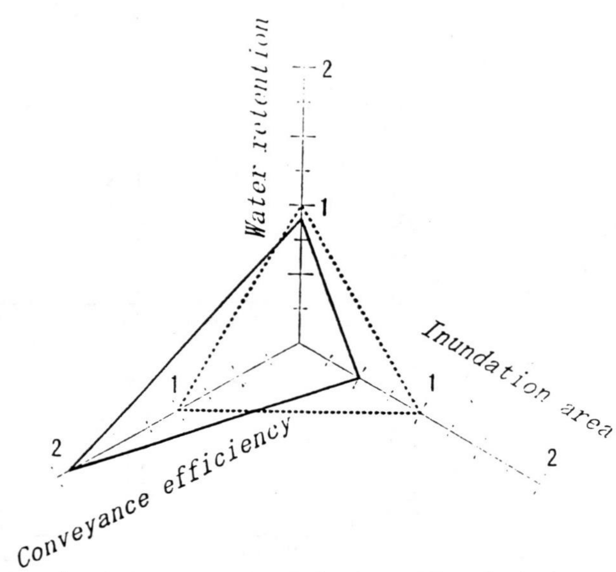

Fig. 11. The functional changes of the Toikanbetsu River basin between pre-settlement (dotted line) and present (solid line). The functions of the basin were estimated from the flood-control point of view.

(Fig. 11). Here, the function of water retention was evaluated by multiplying areas of respective land use by the infiltration rate. The function of inundation was substituted by the area of floodplain without levee construction, and conveyance efficiency was evaluated by dividing annual maximum discharge by corresponding rainfall. The efficiency of the water retention of this basin was not deteriorated significantly since pre-settlement because the forested area has been preserved as the Experimental Forest of Hokkaido University. However, the other functions were significantly reduced by the expansion of agricultural land. Agricultural land developed mainly on the floodplains, and associated flood-prevention dikes removed riparian vegetation. The historical change in the riparian zone is illustrated in Fig. 12. The number of forest patches increased sharply, and total area of riparian forest and the ratio of area to perimeter fell abruptly from 1945 to 1965. Thus, the riparian zone has been shrunk and fragmented. From the previous discussion, I postulate that water temperature of Toikanbetsu River has increased, CWD and litter volume has diminished, and that habitats have been less diverse.

The above example suggests that Japanese flood-prevention technology has offset the historical reduction of retention and inundation functions of a basin by increasing water conveyance efficiency. However, this policy has created an imbalance in functions (Fig. 11), resulting in deterioration of river environment associated with dissipation of riparian structure and function (Fig. 12). Therefore, retrieving the original

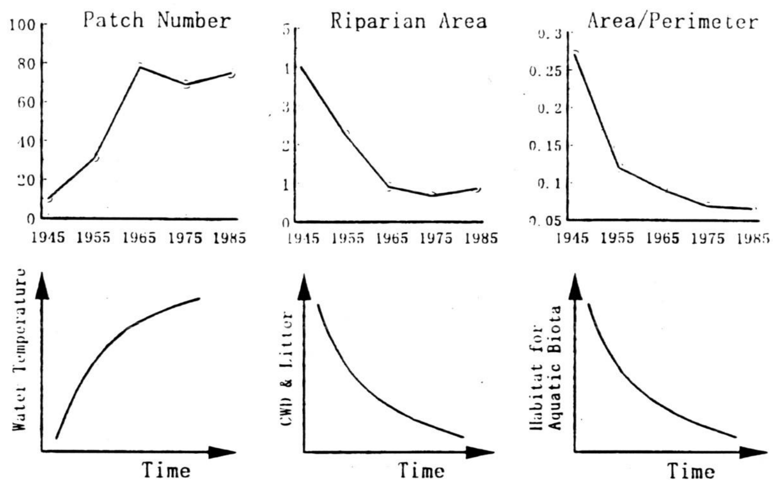

Fig. 12. The shrinkage and fragmentation of the riparian forest of the Toikanbetsu River. The number and area of forest patches were evaluated from aerial-photograph interpretation.

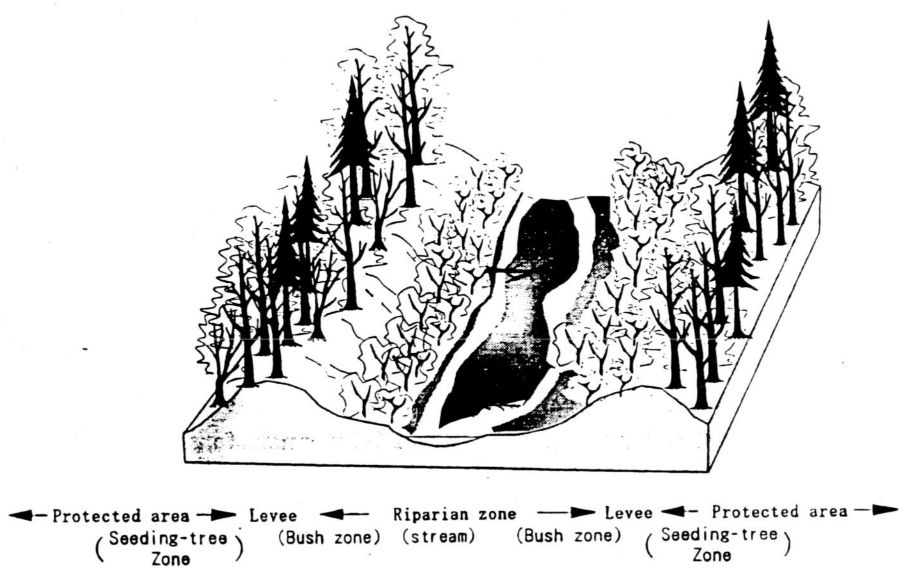

Fig. 13. Restoration of structure and function of riparian zone in urban, embanked areas. Residential sides of levee slopes are used to build seeding-tree zones, and vegetation naturally established between the levees are managed to bushy height to prevent wood-related disaster.

balance in functions by adding landscape elements is the only way to restore river environments. The elements to be introduced should function more efficiently than the original ones, and should vary depending upon land use. I propose the following guideline of river basin management in order to increase water retention and inundation efficiency: 1) preserve the forested area as protection forests in the headwater basins, 2) preserve or create rice fields, natural or artificial ponds, and the belt of riparian forest in agricultural lands in the midstream areas, 3) in downstream urban areas, create the mother-tree zones for supplying seeds to the bush zone (Fig. 13), and provide water retention facilities by digging the ground of playing field and parking lots, which is known as "comprehensive flood control measures" initiated by Japanese Ministry of Construction since 1978.

For the future management policy, main types of linkage te be kept in a river system are upstream and downstream links for material transport, forest and stream interactions, surface water and groundwater interactions affecting water quality, and links between land use planning and river management.

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渓畔域の構造および機能と河川管理への適用

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渓畔域 (riparian zone) の構造を河川地形と植生に区分し，その生態的機能について論じた．河床変動は，渓畔植生が成立する立地基盤を形成し，成立した植生は日射遮断，落葉・落枝供給，CWD (Coarse Woody Debris) 供給，流下物捕捉などの機能を発揮する．これらの機能は渓流の水温，渓流内における一次生産，渓流外からの食物資源量，流砂捕捉，生息場の多様性，土壌養分などに影響し，河川生態系の質を変化させることになる．また河川地形の変化は，落葉落枝・CWD 等の保持に関与し，結果的に水生生物が食物源もしくは生息場として利用するために重要な流下物質の滞留時間に影響を与えている．こうした構造と機能は，対象とする時空間スケールによって異なってくるが，本研究では空間スケールの変化についてのみ検討することにした．その結果，ここで述べた多くの機能は河川サイズ（たとえば河幅）に対して樹木サイズ（たとえば樹高）が相対的に大きい上流域（1次～5次）で影響度が高く，下流に向かって徐々に小さくなると考えられた．今後，こうした構造と機能を維持しながら渓畔域を保存・造成してゆくためには，土地利用によって失われた流域における洪水制御機能のバランスを修正することが重要であると考えた．またそのためには，森林・農地・都市の土地利用に応じたランドスケープ要素（たとえば溜池，貯水池，渓畔林，流出抑制施設など）を保全，もしくは人工的に付加（造成）することを検討しなければならない．

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