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Need for analyzing spatiotemporal patterns of river-corridor habitat structure in sediment management

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ABSTRACT: Spatiotemporal patterns of river-corridor habitat are determined by flow and morphological regimes and they should be integrated in the ecological evaluation. Existing habitat evaluation tools, however, lack this perspective. Even though some recent studies highlighted spatiotemporal patterns, e.g., shifting habitat mosaic steady state concept and habitat age, they do not address processes of changing patterns of each habitat unit, e.g., riffles, side pools, and back waters. We propose a habitat diversity hypothesis, defined as: spatiotemporal patterns of habitat structure determine biological diversity, which can be characterized by a function of intensity and frequency of disturbances and age of each habitat unit from its disturbances. In order to prove our hypothesis, we started a case study in a middle reach of the Tenryu River Japan. Data collected by several interval recording cameras enable to transform into 2D and 3D data and to quantify spatiotemporal patterns.

1 INTRODUCTION

1.1 *Background*

Various habitat evaluation tools have been adopted in decision-making processes in flood and water resources management. For example, Habitat Evaluation Procedures (HEP) quantifies the overall suitability through time by integrating the areal extent-suitability product function over time via habitat suitability indices and thus can quantitatively compare two or more alternative management practices of an area with regards to those practices affecting species (US FWS 1981). Physical Habitat Simulation Model (PHABSIM) predicts physical microhabitat changes associated with flow alternations such as microhabitat, physical habitat and life stage changes (US FWS 1986). Australian River Assessment System (AUSRIVAS) makes an assessment of physical stream condition using the protocol, which requires a large number of reference sites sampled (Parsons, Thoms, & Norris 2001). River Invertebrate Prediction And Classification System (RIVPACS) assesses the biological quality of rivers offering site-specific predictions of the macroinvertebrate fauna to be expected in the absence of major environmental stress (Wright, Sutcliffe, & Furse 2000). Index of Biotic Integrity (IBI) quantifies changes in ecosystem health as a result of habitat degradation or flow alteration, in addition to chronically poor chemical water quality (Karr 1981 & Karr & Dudley 1981). Most of these tools can evaluate current habitat suitability based on physical characteristics or habitat spatial distributions. These tools are useful when comparing several options to determine most appropriate one (s) that can avoid negative consequences to the ecology of rivers and thus often used in decision making processes, e.g., exploring mitigation measures.

Recently, the shifting habitat mosaic steady state concept appeared and it was known as: "Location of aquatic habitats in floodplains changed considerably (turnover), whereas habitat configuration and composition remained relatively stable. These results support the applicability of the shifting mosaic steady-state model to riverine floodplains environments (Arscott et al. 2002)". Further, it is shown that there is a need to address habitat diversity in relation to biological diversity (i.e., species abundance and richness) and there is implication that habitat diversity maximizes biological diversity (Takemon 1997). Further, importance of temporal patterns, i.e., habitat age, was also highlighted (Arscott et al. 2002).

From a different perspective, other studies on analyzing material cycle efficiency showed that habitat structure is considered important for particulate organic material (Ock et al. 2010 and Ock & Takemon 2011), and habitat conditions change in spatial and temporal distributions and thus implicated that temporal patterns are also the key to addressing habitat structure (Takemon et al. 2008). These results explain the importance of considering dynamic state of changing habitat.

Nevertheless, existing habitat evaluation tools lack this perspective: changing habitat in its

Table 1. A review of river restoration projects through channel widening & creating secondary channels for ecological restoration. Particular attention was placed on substantial factors determining the fluvial processes: the river shape, morphological regime, and flow regime. Some projects from USA, Europe, and Japan were selected for the review.

River	Year	Country	Restoration option	Target habitat restored	TP*1	SA*2	FR*3
Drau River	1999	Austria	Secondary channel rehabilitation	River islands and gravel banks	No	No	No
Chikuma River	2006	Japan	Channel widening	Gravel banks	No	No	No
Waar River	1996	Netherlands	Secondary channel creation	Secondary channels	No	No	No
Thur River	2003	Switzerland	Channel widening	Shorelines and gravel banks	No	No	No
Tama River	1996	Japan	Channel widening	Gravel banks	No	Yes	No
Mana River	2003	Japan	Secondary channel creation	Pools, gravel banks, & vegetation	No	Yes	Yes
Trinity River	1991	USA	Channel widening	Riffles & pools and point bars	No	Yes	Yes

*1TP: Temporal patterns of habitat structure were considered.
*2SA: Sediment augmentation was implemented.
*3FR: Flow regimes were modified, e.g., through reservoir operation and managed flows.

habitat age: intensity and turnover rate of spatiotemporal patterns that determine biodiversity.

1.2 *Objectives*

Spatiotemporal patterns are determined by flow regimes and morphological regimes, e.g., deposition and erosion, and sediment transport from upstream. Therefore, they should be integrated in the ecological evaluation. When spatiotemporal patterns are addressed, flow and morphological regimes should be considered as explanatory variables. In this context, firstly we conducted a review on ecological restoration of river corridor habitat, particularly through channel widening and creating secondary channels. We selected well-known restoration projects, which have been implemented in USA, Europe, and Japan (see Table 1). Our particular attention was placed on whether or how flow and morphological regimes are considered to restore fundamental ecological and fluvial processes through particular management options, i.e., reservoir operation and managed flows, and sediment augmentation. Secondly, based on the review, we identified key challenges and propose a habitat diversity hypothesis in order to evaluate spatiotemporal patterns, which is a different approach from the intermediate disturbance hypothesis. Thirdly, in order to prove our hypothesis, we introduce our case study, which started in July 2012 in a middle reach of the Tenyu River in Japan, where several interval recording cameras (hourly) were placed at 60 m high from the riverbed in the center of the river corridor. Through several camera-recording, the photo data can be transformed into 2D and 3D data, enabling to monitor dynamic changing habitat and quantify its spatiotemporal patterns including erosion and deposition processes.

2 ECOLOGICAL RESTORATION: CHANNEL WIDENING AND CREATION OF SECONDARY CHANNELS

2.1 *Drau River in Austria*

The upper Drau in Carinthia had been a highly braided river with many side arms and gravel banks. In the 20th, the riverbed was canalized, bends were straightened out, branches were cut off from the main stream, dams were built, and farming in the floodplain area was intensified. These interventions have brought an enormous loss and degradation of the natural freshwater habitats including alluvial forests and a decline of species populations including the Danube salmon (*Hucho hucho*) and the crayfish (*Austropotamobius pallipes*). Major problems occurred include the deterioration of natural flood retention capacity leading to great risk of flooding. Deepening of the riverbed, e.g., 2 cm per year, caused a fall in groundwater tables (Mohl 2012).

The restoration measures were implemented in from 1999 to 2003 for a river length of 7.6 km as part of the LIFE Nature project "Auenverbund Obere Drau", which became culminated in one of the largest river restoration projects in Europe (Formann et al. 2007). The restoration project aimed to prevent from further riverbed degradation, to re-connect the river with its floodplain area and to initiate the development of typical

Figure 1. Drau river before and after rehabilitation 2003. (Mohl 2012).

habitats of the riverine landscape (see Fig. 1). Bank stabilization structures were removed and the riverbed was widened. Lateral erosion increased the sediment input and initialized the development of gravel/sand bars and islands. One of the former side arms was reconnected to the river for annual flooding. The second side arm was widened to a width of 30 m creating diverse instream structures and thus increasing habitat diversity of the aquatic environment (Mohl 2012). The monitoring of the measures has shown positive results including: better flood prevention; reduced flow velocity; decrease in riverbed deepening even rose; created 50 to 70 ha more natural river habitats as river islands, gravel banks, steep banks for engendered species such as Danube Salmon, Common Sandpiper and Kingfisher created; and fish population doubled such as the grayling (Mohl 2012).

2.2 *Chikuma River in Japan*

The Chikuma River, which is called in the Nagano prefecture, is part of and located a middle reach of the Shinano River that is the longest river in Japan. The Chikuma River has been covered by gravel riverbed and plenty of native plants and animals. However, as same situations as the Tama River (see Section 2.5 for details), intensive gravel miming caused degradation of average riverbed; inundation frequency of floodplains got lost due to development for human use; and embankments and straightening of rivers fixed river morphology, resulting in loss of habitat diversity and native plants. These interventions as a consequence caused increased local sedimentation and nonnative plants, e.g., *Ambrosia trifida* and *Sicyos angulatus*, and woods, e.g., *Robinia pseudocacia* (Chikuma River Ecological Research Group et al. 2010 & Ishikawa et al. 2010).

The Cikumagawa River Works Office of MLIT and Chikuma River Ecological Research Group conducted a river restoration project since 2004 through channel widening with a view to restoring native plants as well as impeding invasion and growth of nonnative plants, as part of riparian forest and river management. The two study sites were selected: the Awasa district conducted in 2006 is located a 81 km point of the Chikuma River, average riverbed slope is 1/510, mean particle size is 40 mm; on one hand, the Nezumi district conducted as the reference site in 2009 is steeper than the Awasa reach located a 98 km point, average riverbed slope is 1/220, mean particle size is 53 mm. were selected in the Chikuma River (see Fig. 2).

The Awasa district restoration showed that channel widening enabled to restore native plants within a short term. A large flood event occurred in July 2006, 3 months after the channel widening, showed that reinvaded nonnative plants were flushed away from the study site and gravel riverbed and aquatic native plants were sustained. This explained the potential to maintain gravel riverbed if widened channel keeps one year frequency of inundation by a certain flood event (annual flood discharge). Small flood events occurred in the Nezumi district also contributed to increasing

Before restoration

Just after restoration. Different types of elevation in channel widening were adopted for the research

Four years after restoration
(a) Awasa district

One year after restoration
(b) Nezumi district

Figure 2. Channel widening of the Chimuma River, illustrating before, just after, and some period after the restoration. (Ishikawa et al. 2010, English words added) Some plants are vegetated in Awasa district (a) the left column, but nonnative plants are not identified even after 4 years after the restoration. Even though a period one year is not long enough after the restoration in Nezumi district (b) a right column, native species are dominant instead of being invaded by nonnative plants.

native plants in stread of allowing for nonnative plants to grow. In addition, at both sites, benthic communities temporarily lost due to channel widening, e.g., *Chironomidae*, *Trichoptera*, and *Ephemeroptera*, were recovered within a few months, implicating further potentials to the outreach of restoration activities.

2.3 *Waar River in The Netherlands*

Garmerensche floodpains are located in the Waar River, a lower reach of the Rhine River in The Netherlands. After a flood event 1995, large amount of clay and sand were excavated and secondary channels were created as part of flood management project including dyke improvement (Baptist & Mosselman 2002). This project also aimed at creating through secondary channels the nature development of flora and fauna as shown in Figures 3 & 4.

Characteristics of the three secondary channels of west, east, and large ones differ: the west and east channels have a sill at the entrance opening that determines the flow frequency; and the larger channel does not have a sill but permanently flows (Baptist & Mosselman 2002).

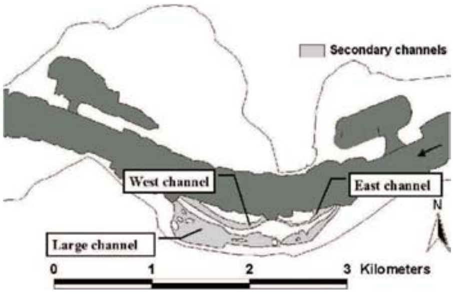


Figure 3. Locations of secondary channels in the Gamerensche floodplains in the Waar River (Baptist & Mosselman 2002).


(a) sedimentation of sand in an intermittently discharging secondary channel

(b) bank erosion near the intake sill of one of secondary channels

Figure 4. Sedimentation and bank erosion occurred at the secondary channels in the Gamerensche floodplains in the Waar River (RIZA 2001, photos taken by Jans L.).

The geomorphological processes were monitored by the Institute for Inland Water Management and Wastewater Treatment (RIZA) and revealed that the east and west channel flow more often than the design frequency. Total sedimentation in the east and west channels since 1996 to 1999 reached to about 5 cm in three years at the entire channels (Baptist & Mosselman 2002). At the same time, secondary channels also caused erosion, where it is not allowed, for example near winter dikes, infrastructure or heavily polluted areas. It may require defense of the banks with stones. Since limits are usually put on the permissible rate of erosion and sedimentation in secondary channels, maintenance measures such as dredging or defending banks can be necessary. It is practically impossible to design stable secondary channels while taking all preconditions into account. Therefore, maintenance activities and monitoring are then needed (RIZA 2001).

2.4 *Thur River in Switzerland*

The Thur River is located in north east of Switzerland, flowing along the Swiss north east Limestone Alps. Switzerland's watercourses have been severely degraded by flood control measures and other engineering operations. This is also true of the Rhone and Thur Rivers, which have largely lost their ecological diversity and characteristic landscape features (Peter 2006). For this reason, increasing efforts have been made to rehabilitate watercourses by the Rhone-Thur research project. The aim of this project is to remedy deficiencies in the existing flood control system and, at the same time, to enhance the Rhone ecologically. Figure 5 shows the Thur River at Altikon-Niederneunforn before


(a) Before rehabilitation June 2001

(b) 2 years after rehabilitation September 2005

Figure 5. Thur River at Altikon-Niederneunforn before and after the channel widening (Peter 2006 including photos).

and after the channel widening (Peter 2006). This channel widening involved a stretch of 1.5 km of the river, which was the most extensive local widening project in Switzerland. Particularly increase in shoreline length resulting from the development of gravel banks can be highlighted. The new habitat types that emerged were rapidly colonized by plants and wildlife (REFORM 2012).

In this Rhone-Thur research projects, ecological success by channel widening of five river stretches were assessed in detail before and after widening: the Emme at Aefligen, the Thur at Gütighausen, the Rhone at Chippis, and the Moesa at Grono and Lostallo. The indicators chosen for this purpose were parameters that describe landscape structure, e.g., habitat type, diversity, size and shape, distance between two areas of a given habitat type, and habitat boundary length (Rhode 2004 & 2006). For the assessment, values were determined for the indicators and were transferred to a unitless index, with a scale from 0 to 1. The value "0" represents the initial channelized state, and "1" the desired near-natural target state. Through the assessment, the channel widening achieved a relatively high degree of naturalness (Rhode 2004 & 2006).

The assessment indicated that the remaining deficiencies in comparison with near-natural reference sites are due to the lower habitat diversity and patchy structure arising from the limited spatial extent of the widening. The Thur stretch was found to be less successful as compared to other sites. This is partly due to the fact that the gravel bars at this site are less substantial and thus more frequently flooded (Rhode 2004 & 2006). It is important to identify stretches of rivers that are particularly suitable for channel widening on account of favorable ecological conditions and thus appear to offer good prospects of success (Rhode 2006).

2.5 *Tama River in Japan*

The Tma River has been most consisted of gravel riverbed in Japan and is under management of Ministry of Land, Infrastructure, Transport and Tourism (MLIT), of which: catchment area is 1240 km^2; river length is 138 km including major tributaries; average bed slope is 1/218; and river width is approximately 300 m in mean annual flood discharge (almost bankfull) of 1300 m^3/s. The Tama River has formed gravel bars mostly braided and has provided habitat for native plants and animals requiring gravel riverbed, e.g., *Aster kantoensis*, in 1950s (Nakamura et al. 2006). However, intensive human interventions made in 1960s to 1990s altered fluvial processes by: e.g., gravel bed mining prohibited in 1965 (most severely affected); construction of the Okouchi dam in 1957; and fixing of river shapes by embankments, straightening, and creation of less frequently inundated area for human use such as parks, camping area, and baseball and football fields. Such human interventions caused: reduced sediment supply from upstream (particularly coarse sediment but not fine one), leading to degradation of average riverbed elevation; reduced inundation and disturbance on floodplains, resulting in intensive fine sediment deposition on relatively higher floodplains where are less frequently inundated; increased nonnative woods (e.g., *Robinia pseudocacia*) thereon replaced with native plants; and thus loss of habitat and species diversity of rivers (see Fig. 6).

The gravel-bar restoration project was conducted in the Nagata district of the Tama River, with a view to increasing frequency of floodplain inundation by channel widening and thereby restoring gravel-bars, native plants, and species dependent on such gravel-bars (Shimatani 2003 & Unno et al. 2006). The restoration projects have started since 1996 by the Keihin River Works Office of MLIT and Tama River Ecological Research Group. Characteristics of the project are composed of two parts: (i) channel widening was made at 52 to 53 km points in which different five types of bed elevation (i.e., different inundation frequency) were selected and (ii) sediment augmentation was installed at 3 km upstream of the restored reach of a 56 km point (see Fig. 7).

The results showed positive consequences. Gravel-bed restoration through channel widening increased native plants and species, e.g., *Aster kantoensis* and *Charadrius placidus*. The widened channel shape became stable and slightly deposited. Sediment augmentation of 5000 m^3 per year upstream has the potential to stabilize the riverbed elevation (Unno et al. 2006).

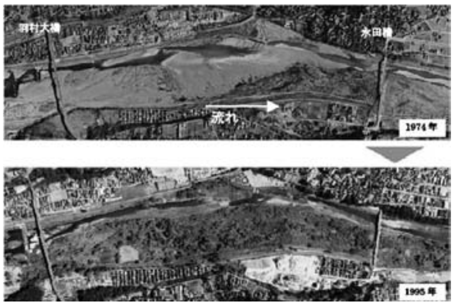


Figure 6. Aerial photos of Nagata district in 1974 and 1995 (Unno et al. 2006). The gravel bed on the right floodplains 1974 was replaced with vegetation and tree covers 1995. Fine sediment was severely deposited on the right side and frequency of inundation was drastically reduced.

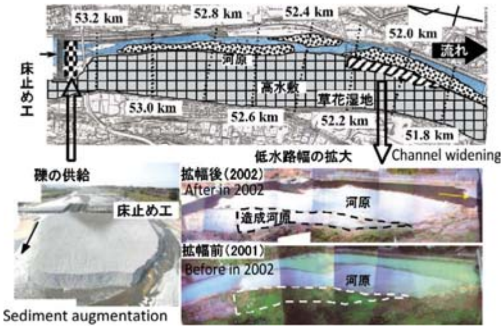


Figure 7. Channel widening and sediment augmentation in 2001 (Unno et al. 2006, English words added). Sediment augmentation (see the photo of the left bottom) was carried out 3 km upstream of the study reach at the amount of 1800 m^3 in Feb. 2001, 4000 m^3 in Feb. 2002, 400 m^3 in May 2002, and 4300 m^3 in Feb. 2003.

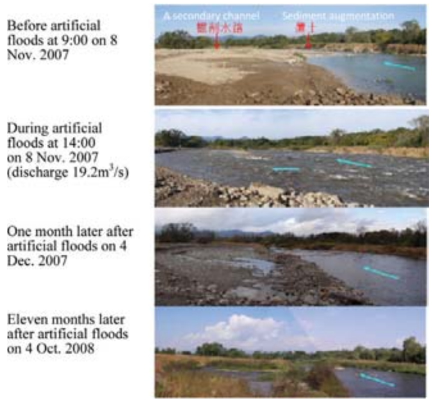


Figure 8. Monitoring results of rehabilitated the secondary channel and sediment augmentation (Kumagai 2009).

2.6 *Mana River in Japan*

The Mana River is located in the Fukui prefecture, flowing to the Kuzuryu River. In the upstream of the Mana River, several dams are constructed: from the upper reach, the Kumokawa dam in 1956, Sasogawa dam in 1965, and Managawa dam in 1979 at the downstream reach, 14 km from the Kuzuryu River. These dams play important roles in flood mitigation and electric supply for the Fukui city. Since the Mana River does not have relevant tributaries below the Managawa dam until it meets the Kuzuryu River, it causes negative impacts such as fixing of river shape, processing riverbed armoring, resulting in coarse sediment not allowing for fluvial processes, and intense vegetation and wooden floodplains (Kumagai 2009).

The Kuzuryu Dam River Office of MLIT has started a restoration project. Artificial floods via reservoir operation have been carried out since 2003 and maximum 45 m^3/s flood discharge for 2.5 hours was installed since 2006. This flood discharge was adopted based on a result of previous studies that attached algae to sediment can be flushed and thus effective for restoring morphological regimes of the Mana River (Sakamoto et al. 2006).

In 2007, rehabilitation of a secondary channel and sediment augmentation were integrated into artificial floods with a view to restoring gravel riverbed, instead of intensive invasion of woods onto floodplains, habitat diversity, and habitat preferred to fish communities (see Fig. 8). A secondary channel created at the middle reach of the Mana River upstream of the Kimigayo bridge has the channel width of 20 m, length of 100 m, riverbed slope of 1/82 as the same slope as the main channel, and deepened down to a elevation that does not allow for flowing less than mean flow discharge. The sediment augmentation of 330 m^3, consisted of excavated sediment for the secondary channel and deposited sediment of the Managawa dam, was placed with the width of 10 m (i.e., one third width of the main channel), its length of 10 m at the main channel, and inundated at peak discharge of artificial floods (Kumagai 2009).

The results showed, for example in 2007, that: a deep pool was created at the entrance of the secondary channel; gravel bars were created at its outlet; and 115 m^3 of sediment placed were flushed downstream. The monitoring results identified increased vegetation, and increased habitat diversity in the form of a pool and gravel bars, and species diversity in response to benthic communities between the main and secondary channel. This restoration project through integration of channel rehabilitation, artificial floods, and sediment augmentation implicates its potential to become a trigger for restoring morphological regimes and creating habitat diversity suitable for fish and benthic communities (Kumagai 2009).

2.7 *Trinity River in California, USA*

The Trinity River begins in the rugged Trinity Alps in northwestern California. It tumbles through steep canyons and meanders through broad valleys until it joins with the Klamath River to flow into the Pacific Ocean. In 1958, a plan was executed to increase water supplies in California's Central Valley in part by transferring water from the Trinity River into the Sacramento River known as Trinity River Division (TRD). This diverts 90% of the river's flow exported from the river each year. Trinity and Lewiston dams were also completed in 1964. The impacts of land use and dams combined to push the river past its regenerative capacity. After the dams were completed, the extent of habitat alteration and decline in salmon and steelhead populations became obvious by 1970.

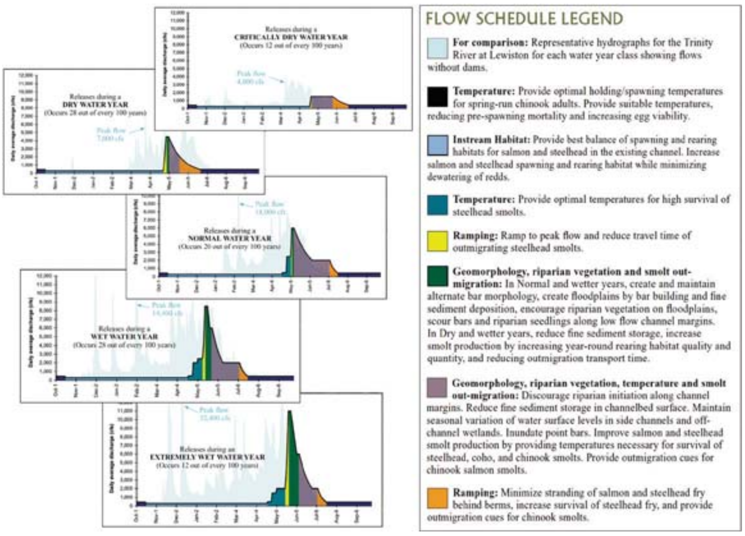
The plan is to implement recovery of the Trinity River and its fish and wildlife populations. Restoring the Trinity River requires a combination of actions that: re-establishes the natural physical processes that creates and maintains high quality aquatic habitat; and creates spawning and rearing conditions downstream of the dams that best compensate for lost habitat upstream, including adequate water temperatures (McBain & Trush, Inc. 2000). This strategy does not strive to recreate pre-dam conditions, but rather to create a dynamic alluvial channel, exhibiting all the characteristics of the pre-dam river but at a smaller scale. Particular attention was placed in the project to, but not limited to: channel rehabilitation, flow management, and sediment augmentation. Channel rehabilitation removed riparian berms that confine the river, and relocated sand contained in the berm outside of the floodway (Figs. 9 & 10).

Floodplains will be constructed to be periodically inundated by flows 170 m^3/s and larger. Then it is expected to create riffles, pools, and gravel/cobble point bars, improve channel dynamics, and increase salmon spawning and rearing habitat. Observations at rehabilitation sites constructed between 1991 and 1993 have shown that once the riparian berm is removed and new bars have formed, flow and coarse sediment management is capable of maintaining the desirable channel morphology (McBain & Trush, Inc. 2000).

For flow management, in order to recreate inter-annual, or "between-year" flow variability, five water year types with a minimum volume of water to be released into the Trinity River were designed as shown in Figure 11. The quantity and quality

Figure 9. Sheridan Creek Bank rehabilitation site with newly formed gravel bars. (McBain & Trush, Inc. 2000).

Figure 10. Sketch of channel rehabilitation. (McBain & Trush, Inc. 2000).



FLOW SCHEDULE LEGEND

■ **For comparison:** Representative hydrographs for the Trinity River at Lewiston for each water year class showing flows without dams.

■ **Temperature:** Provide optimal holding/spawning temperatures for spring-run chinook adults. Provide suitable temperatures, reducing pre-spawning mortality and increasing egg viability.

■ **Instream Habitat:** Provide best balance of spawning and rearing habitats for salmon and steelhead in the existing channel. Increase salmon and steelhead spawning and rearing habitat while minimizing dewatering of redds.

■ **Temperature:** Provide optimal temperatures for high survival of steelhead smolts.

■ **Ramping:** Ramp to peak flow and reduce travel time of outmigrating steelhead smolts.

■ **Geomorphology, riparian vegetation and smolt out-migration:** In Normal and wetter years, create and maintain alternate bar morphology, create floodplains by bar building and fine sediment deposition, encourage riparian vegetation on floodplains, scour bars and riparian seedlings along low flow channel margins. In Dry and wetter years, reduce fine sediment storage, increase smolt production by increasing year-round rearing habitat quality and quantity, and reducing outmigration transport time.

■ **Geomorphology, riparian vegetation, temperature and smolt out-migration:** Discourage riparian initiation along channel margins. Reduce fine sediment storage in channelbed surface. Maintain seasonal variation of water surface levels in side channels and off-channel wetlands. Inundate point bars. Improve salmon and steelhead smolt production by providing temperatures necessary for survival of steelhead, coho, and chinook smolts. Provide outmigration cues for chinook salmon smolts.

■ **Ramping:** Minimize stranding of salmon and steelhead fry behind berms, increase survival of steelhead fry, and provide outmigration cues for chinook smolts.

Figure 11. Flow schedules of five water year types in intra-annual or "within-year" flow valiability (McBain & Trush, Inc. 2000). Note: 1 Cubic Foot = 0.0283168466 Cubic Meters.

of spawning and rearing habitat for salmon and steelhead varies with flow levels. The relationship between streamflows and habitat, developed during years of the field study, was used to determine the preferred flow releases for riverine life stages of chinook salmon, coho salmon, and steelhead. Habitat is maximized at 4.2 m^3/s for some life stages and at higher flows for others. Within the existing channel, 8.5 m^3/s provides the best balance for juvenile rearing and adult spawning habitat (McBain & Trush, Inc. 2000).

Coarse sediment management is to increase coarse sediment storage in the river (gravel/cobble bars), improve coarse sediment transport, and restore a balance between coarse sediment supply and coarse sediment transport using high flows and mechanical gravel introduction. If the river were considered a conveyor belt periodically transporting and depositing coarse sediment, the proposed restoration strategy would add coarse sediment at the upstream end of the conveyor belt at a rate equal to what the conveyor is moving, such that accumulations (at tributary deltas) or deficits (channel incision and armoring) are minimized (McBain & Trush, Inc. 2000).

3 HABITAT DIVERSITY HYPOTHESIS

3.1 *The analysis of the review*

All the seven case studies on ecological restoration in USA, Europe, and Japan have been addressing restoration of some parts of spatial habitat structure, depending on their project scale and goals such as: gravel banks (e.g., Drau River, Chikuma River, Thur River, Tama River, and Mana River) and riffles and pools (e.g., Mana River and Trinity River). However, approaches to achieving their goals are different. While some projects addressed only modifying river shapes locally (e.g., Thur River, Drau River, Waar River, and Chikuma River), but the other projects addressed operation of flow or morphological regimes in an integrated manner (e.g., Trinity River, Tama River and Mana River). Only two case studies of the Trinity River and Mana River integrated restoration of both flow and sediment regimes into their restoration projects (see Table 1). From a perspective of temporal patterns, little case studies addressed temporal change of habitat structure, except for some local deposition and erosion processes. Through the review, we found that flow and morphological regimes, which can be considered as explanatory variables for spatiotemporal patterns of habitat structure, have been addressed by only a few case studies. In the review however, it should be noted that: case studies are in the ongoing processes of determining desirable spatiotemporal patterns of river corridor habitat and how they are evaluated; and that options for ecological restoration should be adopted based on appropriate combination of flow and morphological regimes (Kantoush et al. 2011 and Sumi & Kantoush 2012). Importantly, for some case studies, flood management objectives are at center of their restoration projects (e.g., Drau River and Chikuma River) based on a concept that restoring some part of fluvial processes can contribute to, for example, lowering of water stages during flooding, instead of constraining flood water in channelized embankments.

Various existing ecological evaluation tools, as discussed in Section 1.1 address spatial distributions of habitat structure but do not address spatiotemporal patterns of changing habitat. There is, therefore, a need for analyzing spatiotemporal patterns of habitat structure. However, questions may be raised: how dynamic state of changing habitat can be evaluated and integrated into restoration projects; and how goals for successful restoration can be set.

3.2 *Habitat diversity hypothesis*

Intermediate disturbance hypothesis is one of keys to discussing evaluation of species richness, originally developed for marine intertidal communities (Connel 1978). This hypothesis explains that disturbance of intermediate intensity and frequency will maximize species richness by reducing density of dominant species and create habitat for more fugitive species in inter-specific competition. However, since some communities of species can exist in intermediate disturbances, another approach to evaluating biological diversity may be needed rather than a concept of inter-specific competition. Other studies showed that there is a need to address habitat diversity in relation to biological diversity (i.e., species abundance and richness) and there is implication that habitat diversity can maximize species diversity (Takemon 1997). A study conducted in rivers in New Zealand showed that ratio of surface sediment in its relation to species richness had similar results with the habitat disturbance hypothesis (Townsend et al. 1997 and Matthaei et al. 1999). Even though this result does not analyze relations between habitat diversity and species diversity, it implicates the possibilities. Therefore, spatial heterogeneity should be addressed.

On one hand, temporal patterns are also highlighted. The shifting habitat mosaic steady state concept, addressing some parts of temporal patterns, explains that habitat changes in shifting mosaic and assembles of spatial distributions of habitat structure get almost stable and this steady state supports riverine environment (Arscott et al. 2002). Habitat age is another approach that analyzes continuity of habitat structure in a reach and understands that existence of diversity of habitat age in a reach supports species diversity (Arscott et al. 2002). An attempt to address temporal patterns in form of habitat age is important, however, this neither tracks processes of temporarily changing patterns of each habitat unit, e.g., riffles, pools, side pools, and back waters, nor addresses quality of changing habitat, i.e., changing patterns of microhabitat in each habitat unit (macro habitat). The discussions above highlighted a need for analyzing spatiotemporal patterns of river corridor habitat structure, in which flow and morphological regimes can be explanatory variables.

We propose the "*habitat diversity hypothesis*" to analyze spatiotemporal patterns of habitat structure. We define the *habitat diversity hypothesis* as: Spatiotemporal patterns of habitat structure determine biological diversity (i.e., species abundance and richness), which can be characterized by a function of intensity and frequency of disturbances and age of each habitat unit from its disturbances. Then if intermediate disturbances enhance habitat diversity, it is prerequisite for proving the following two aspects:

- Biological diversity is maximized by spatial heterogeneity, defined as "*spatial heterogeneity hypothesis*"; and
- There are disturbance regimes, which maximize biological diversity in temporal heterogeneity of habitat conditions, i.e., disturbance intensity and frequency and age of each habitat unit, defined as "*temporal heterogeneity hypothesis*".

Our approaches to prove these hypotheses can be explained. *Spatial heterogeneity hypothesis* can be proved by analyzing whether resultant habitat diversity, which maximizes biological diversity, is characterized by intermediate disturbances. *Temporal heterogeneity hypothesis* can be proved by developing a series of special distributions of each habitat unit and its age and analyzing conditions that maximize biological diversity. We identify *spatial heterogeneity hypothesis* and *temporal heterogeneity hypothesis* are substantial components of *habitat diversity hypothesis*.

4 AN ATTEMPT TO ANALYZE SPATIOTEMPORAL PATTERNS IN THE TENRYU RIVER

In order to prove the *habitat diversity hypothesis* discussed above, we started a case study in July 2012 in a middle reach of the Tenryu River Japan, of which the riverbed is likely to move by a certain discharge. There is a similar case study, which analyzes spatiotemporal patterns using interval-recording cameras in the Tagliamento River Italy (for example, Arscott 2002). This study is effective to gain plenty of qualitative data through photos but cannot quantify quantitative data, e.g., area of changing habitat and deposition and erosion processes. In the Tenryu River, in respect to the Tagliamento study, photogrametric mthods are used as a challenge to solve the problems. Data has been collected on spatiotemporal patterns by several interval recording cameras (hourly) placed at 60 m high from the riverbed in the center of the river corridor. Several camera-recording can transform photos into 2 D, i.e., ortho data, and 3 D data, enabling to quantify the spatiotemporal patterns including erosion and deposition processes, using photogrametoric methods. Figure 12 shows a view of recorded photo data capturing upstream of the Tenryu River in (a) and transformed results for analyzing spatiotemporal patterns in (b) and (c), where the camera view is transformed into 2 D and 3 D data. This article is kept up to introduce our attempt to be

(a) A view from the tower conducting interval recording through camera monitoring.

(b) Camera recording data transformed into 2D ortho data using photogrametoric methods. The accuracy of this ortho data is kept almost 1 m.

(c) Camera recording data transformed into 3D data, a photo taken on 10 December 2012. Further improvement required.

Figure 12. Recorded photo data taking upstream of the Tenryu River and transformed results for analyzing spatiotemporal patterns.

made, methodologies and results of which will be reported in another article.

5 CONCLUSIONS

The review revealed that spatiotemporal patterns, determined by flow and morphological regimes, should be integrated into restoration projects depending on its scales and objectives. We propose the *habitat diversity hypothesis* as a different approach from the intermediate disturbance hypothesis, which explains biological diversity composed of two aspects: *spatial heterogeneity hypothesis* and *temporal heterogeneity hypothesis*. We started a case study in the Tenryu River via interval-recording cameras. This study can be a new approach to analyzing spatiotemporal patters of habitat structure quantitatively, through which spatial and temporal patterns are expected to be inter-woven.

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REFERENCES

Arscott, D., Tockner, K., Nat, D., & Ward, J. 2002. Aquatic Habitat dynamics along a Braided Alpine River Ecosystem (Tagliament River, Northeast Italy), Ecosystems 5, 802–814, DOI: 10.1007/s10021-002-0192-7.

Baptist, M.J., & Mosselman, E. 2002. Biogeomorphological modelling of secondary channels in the Waal river. In: D. Bousmar & Y. Zech, (eds.), River Flow 2002 Symposium: 773–782, Louvain-la-Neuve, Belgium.

Chikima River Ecological Research Group, Nakamura K., & Kawaguchi K. 2010. The status and outcomes of the Chikuma River Ecological Research, Riverfront 2010 Vol. 68, 8–13 [all in Japanese including the title].

Connel, J.H. 1978. Diversity in Tropical Rain Forests and Coral Reefs, High diversity of trees and corals is maintained only in a nonequilibrium state, Science Vol. 199, 1302–1310.

Formann, E., Habersack, H.M., & Schober, St. 2007. Morphodynamic river processes and techniques for assessment of channel evolution in Alpine gravel bed rivers, Geomorphology 90 (2007) 340–355.

Institute for Inland Water Management and Waste Water Treatment (RIZA), 2001. Guidelines for rehabilitation and management of floodplains Ministry of Transport, Public Works and Water Management, RIZA report: 2001.059, ISSN 1568-234X.

Ishikawa, T., Shimizu T., & Niimura N. 2010. Establishment of countermeasures for nonnative plants and riparian forest management to reduce maintenance cost in river management, Chikumagawa River Office, Hokuriku Regional Development Bureau of Ministry of Land, Infrastructure, Transport and Turism, Japan [all in Japanese including the title], found as of 31 December 2012 on the website: www.hrr.mlit.go.jp/library/kenkyukai/h22/kankyou/11.pdf.

Jans, L., Backx, J., Greijdanus-Klaas, M., de Jonge, J., van der Meij, V., Oosterbaan, J., van der Scheer, A., & Schropp, M. en M. van Wijngaarden, M., 2001. Monitoring Nevengeulen. Integrale Jaarrapportage 1999/2000. RIZA Werkdocument 2001.062x. RIZA, Lelystad.

Kantoush, S.A., Sumi, T., & Takemon, T. 2011. Lighten the load, International Water Power & Dam Construction, May, pp. 38–45.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. Fisheries 6, 21–27.

Karr, J.R. & D.R. Dudley. 1981. Ecological perspective on water quality goals. Environ. Manage. 5, 55–68.

Kondolf, G.M., & Minear, J.T. 2004. Coarse Sediment Augmentation on the Trinity River Below Lewiston Dam: Geomorphic Perspectives and Review of Past Project.

Kumagai, H. 2009. Approaches to ecological restoration by artificial floods from the Managawa dam [in Japanese], Kinki Regional Development Bureau of the Ministry of Land, Infrastructure and Transport, found as of 31 December 2012 on the website: http://www.kkr.mlit.go.jp/plan/happyou/thesises/2009/pdf02/08.pdf.

Matthaei, C.D., Peacock, K.A., & Townsend, C.R. 1999. Patchy surface stone movement during disturbance in a New Zealand stream and its potential significance for the fauna, Limnology and Oceanography 44(4), pp. 1901–1102.

McBain & Trush, Inc. 2000. Trinity river restoration program, summary of the United State Secretary of the Interior Record of Decision.

Mohl, A. 2012. LIFE River restoration projects in Austria, found as of 26 December 2012 on the website: http://www.biomura.si/prenosi/Izvananje%20projekta/LIFE%20River%20restoration%20projects%20in%20Austria/Life%20Riever%20restoration%20projects%20in%20Austria.pdf.

Nakamura, K., Tockner, K., & Amano, K. 2006. River and Wetland Restoration: Lessons from Japan, Bioscience Vol. 56 No. 5, 419–429.

Ock, G., Muto, Y., Sumi, T., & Takemon, Y. 2010. Roles of Riffle and Pool Structure in Particulate Organic Matter Dynamics in the Downstream Reaches of Dam Reservoirs, Annuals of Disaster Prevention Research Institute, Kyoto University, No. 53 B, 773–782.

Ock, G. & Takemon, Y. 2011. Relation of Hydrogeomorphology of Gravel Bar in Particulate Organic Matter Dynamics in Braided Alpine River, Annuals of Disaster Prevention Research Institute, Kyoto University, No. 54 B, 727–733.

Parsons, M., Thoms, M., & Norris, R. 2001. Australian River Assessment System: AusRivAS Physical Assessment Protocol, National River Health Program, Environmental Australia.

Peter, A. 2006. Rehabilitation- to What Extent, and Why?, Eawag News 61e. Flood Protection and Rehabilitation—New Direction for Our Rivers.

REFORM, 2012. River Drau—Austria, Flagship restoration measure, found as of 26 December 2012 on the website: http://www.reformrivers.eu/river-drau-%E2%80%93-austria-flagship-restoration-measure.

Rohde, S. 2004. River Restoration: Potential and limitations to re-establish riparian landscapes. Assessment & Planning., a dissertation submitted to the Swiss Federal Institute of Technology Zurich for the degree of science.

Rohde, S. 2006. Widening as a Rehabilitation Measure, Eawag News 61e. Flood Protection and Rehabilitation —New Direction for Our Rivers.

Sakamoto, H., Nakamura, J., Sumi, T., & Azami, K. 2006. Planning and evaluation method for "flushing flow" under the trial of flexible operation of Managawa dam, Kasen gijutu ronbun shu [in Japanese], Vol. 12, 271–276, Japan Society of Civil Engineers.

Shimatani, Y. 2003. Conservation and Resroration of River Environment, Ecology and Civil Engineering 5(2), 223–240 [in Japanese with English abstract].

Sumi, T., & Kantoush. S.A. 2010. Integrated Management of Reservoir Sediment Routing by Flushing, Replenishing and Bypassing Sediments in Japanese River Basins, 8th International Symposium on Ecohydraulics, CD-ROM.

Takemon, Y. 1997. Management of biodiversity in aquatic ecosystems: dynamic aspects of habitat complexity in stream ecosystems. In: (ed. by Abe T., Levin S., & Higashi M.) Biodiversity: An Ecological Perspective. Springer, 259–275.

Takemon, Y. 2007. Ecology and Civil Engineering as a science of habitat, Ecology of Civil Engineering. 10(1), 41–46, Japan.

Takemon, Y. 2008. Spatial distribution patterns of allochtonous and autochtonous benthic particulate organic matter on the riverbed of a mountain stream in Kyoto, Japan, Water Down Under 2008, pp. 2393–2403.

Townsend, C.R., Scarsbrook M.R., & Doledec S. 1997. The intermediate disturbance hypothesis, refugia and biodiversity in streams, Limnology and Oceanography 42, pp. 938–949.

Unno, S., Saida, K., Ise, T., Suetsugi, T., Fukushima, M.K., & Fujimoto, M. 2006. Change of biological community and bed topography after the gravel-bar restoration work on the Nagata district in the Tama River, Ecology and Civil Engineering 9(1), 47–62 [in Japanese with English abstract].

U.S. Fish and Wildlife Service. 1981. Standards for the development of habitat suitability index model for use in the Habitat Evaluation Procedures, USDI Fish and Wildlife Service, Division of Ecological Services. ESM 103.

U.S. Fish and Wildlife Service. 1989. Physical Habitat Simulation System Reference Manual Version II. Instream Flow Information Paper No. 26.

US Secretary of the Interior. 2000. Trinity river restoration program, Summary of the US Secretary of the Interior, Record of Decision.

Wilson, J.B. 1990. Mechanisms of species coexistence: twelve explanations for Hutchinson's 'paradox of the plankton': evidence from New Zealand plant communities. New Zealand Journal of Ecology, 13, 17–42.

Wright, J., Sutcliffe, D., & Furse, M. 2000. Assessing the biological quality of fresh waters: RIVPACS and other techniques, Freshwater Biological Association.