

Enhanced Diversity at Network Nodes: River Confluences Increase Vegetation-Patch Diversity

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Abstract: Although dendritic networks within ecosystems have typically been considered a special case of network topology, they have attracted a great deal of attention in recent years. These systems exhibit unique features in that both the nodes and branches provide distinct habitats. Within a river discontinuum context, river confluences, which are nodes of dendritic river networks, are hypothesised to have particular hydrodynamic traits that create heterogeneous habitats through a unique disturbance regime, although this hypothesis has not yet been tested. We tested this hypothesis using a vegetation data set collected from 14 river basin systems in Hyogo Prefecture, Japan. We compared vegetation-patch diversity between confluence and single-flow areas using hierarchical Bayesian models. Our results demonstrated greater vegetation-patch diversity in confluence areas compared to single-flow areas. Our findings support the hypothesis that confluences result in highly heterogeneous habitats. To the best of our knowledge, this is the first empirical report to demonstrate that river confluences have high vegetation-patch diversity. We conclude that network nodes play an important role in maintaining the biodiversity of river networks.

Keywords: Disturbance, geography, habitat heterogeneity, hierarchical Bayesian model, river channel network.

INTRODUCTION

Recent syntheses have used network theoretical analysis to understand the functioning of diverse sets of complex ecological systems (May 2006; Montoya *et al.* 2006). These analyses have suggested that emergent characteristics such as system-level responses to disturbance can be predicted from the structure of a network and the strength of interactions among network elements (Grant *et al.* 2007). Although dendritic networks within ecosystems are usually considered a special case of network topology (Grant *et al.* 2007), they have attracted a great deal of attention in recent years. Such systems exhibit the distinctive feature that both the nodes and branches provide unique habitats (Benda *et al.* 2004a; Benda *et al.* 2004b; Grant *et al.* 2007).

In dendritic networks, nodes provide high-quality habitats (Grant *et al.* 2007). River confluences, which correspond to the nodes of dendritic river networks, are known to exhibit particular hydrodynamic traits (Rhoads & Kenworthy 1995; De Serres *et al.* 1999; Benda *et al.* 2004a; Benda *et al.* 2004b; Rice *et al.* 2008) that result in many geomorphically diverse habitats (Benda *et al.* 2004b; Rice *et al.* 2008). In river ecosystems, flooding-induced disturbances, which pro-

vide the most dynamic and complex biophysical habitats (Naiman *et al.* 1993; Burkart 2001), occur more frequently at confluences (Benda *et al.* 2004b). Thus, confluences are considered to increase spatial and temporal habitat heterogeneity (Benda *et al.* 2004a; Benda *et al.* 2004b; Rice *et al.* 2008). Benda *et al.* (2004a, b) reviewed several cases of habitat creation by confluences, e.g., the formation of fans and erosion-resistant deposits, which may influence biodiversity (Benda *et al.* 2004a; Benda *et al.* 2004b). However, the roles of confluences in creating habitat heterogeneity (confluence effects) within river ecosystems have rarely been examined, but they should be investigated within a context of maintaining biodiversity in river ecosystems.

Habitats in river systems are characterised by differences in river streams and reaches, which join together to form larger networks (Lowe *et al.* 2006). Therefore, an effective analysis of the ecological importance of a river confluence as a component of the river channel network must incorporate the entire river channel network. Ideally, this kind of analysis applies data collected from many rivers that constitute various river channel networks (Benda *et al.* 2004b). This type of approach helps to minimise individual river system-specific “noise” when analysing confluence effects (Knick *et al.* 2008). However, few wide-area biodiversity data sets from many river systems are available, because data collection is often expensive and time-consuming (e.g., Svensson *et al.* 2007; Haddad *et al.* 2008). From 2002 to 2006, the Hyogo Prefecture government in Japan conducted the Research about the Natural Environment of Rivers (RNER)

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program for all rivers within the prefecture. This program involved investigating riparian vegetation for 195 individual rivers in 14 river basin systems, over an area of 5105 ha. All data were digitised and then incorporated into a geographic information system (GIS) (Hyogo Prefecture 2007). We used the RNER riparian vegetation data to determine whether diversity in vegetation patches, which serve as potential habitat, increases around confluences of Hyogo Prefecture rivers. High physical heterogeneity may augment biological diversity via the well-established principle that biological diversity tends to increase with habitat variability (Benda *et al.* 2004b; Rice *et al.* 2008).

We analysed the RNER data set to determine how river confluences affect habitat heterogeneity using a hierarchical Bayesian model that included three hierarchical random effects (see “METHODS” section). In the RNER vegetation data set, different vegetation types were illustrated as patches on a vegetation map. The 17 vegetation types correspond to different habitat types in the RNER (Hyogo Prefecture

2009). We used Shannon and Simpson diversity indices of vegetation patches as indices of habitat diversity and compared these between confluence sites and non-confluence sites. The following sections present our findings and discuss the significance of river confluences in riparian ecosystems.

METHODS

Research About the Natural Environment of Rivers (RNER) Data Set

We used the RNER vegetation data set from surveys conducted between 2002 and 2006 (Fig. 1) to investigate riparian vegetation in alluvial river sections (total length, 680 km). The RNER vegetation data set was created using two steps. The first step involved identification of the edges of vegetation patches from aerial photographs and digitalisation of vegetation patches on a 1/2500 contour map. Color photographs (scale: 1/10,000) taken by the Hyogo Prefecture

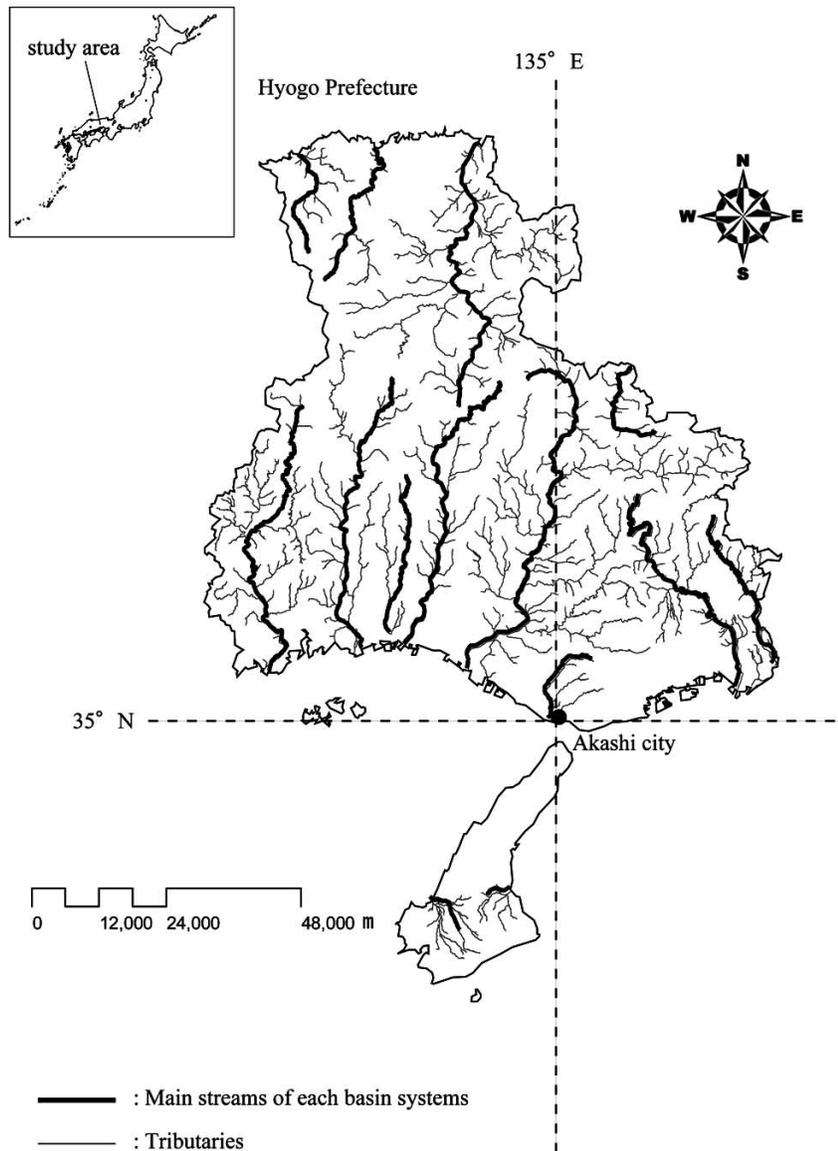


Fig. (1). Watersheds and main streams of analyzed river basin systems in Hyogo Prefecture.

Table 1. Vegetation types in the RNER Data Set and Explanation of Indication Habitats. Definitions are Detailed in Hyogo Prefecture (2009)

| No. | Vegetation type | Habitat type as indicated by the vegetation type |
|-----|---|--|
| 1 | <i>Miscanthus sacchariflorus</i> dominant vegetation | Sandy habitats frequently found in relatively gentle river inclination (1/1000-1/250) areas |
| 2 | <i>Phragmites communis</i> dominant vegetation | Muddy wetland habitats found in areas with low flow velocity |
| 3 | <i>Phragmites japonica</i> dominant vegetation | Frequently disturbed rudaceous habitats widely distributed in steeper river inclination (1/300-) areas |
| 4 | <i>Salix gracilistyla</i> dominant vegetation | Frequently flooded riverside habitats often found in steeper river inclination (1/200-) areas |
| 5 | Floating-leaved and submerged plant vegetation | Stagnant water and slow-current habitats |
| 6 | Halophytic plant vegetation | Habitats preferred by halophytic plants |
| 7 | Sand dune vegetation | Habitats similar to coastal sand dunes |
| 8 | Vegetation beside mountain stream | Stable wet habitats maintained by droplets of flow and/or bubbled-up water. |
| 9 | Riparian forest vegetation | Wet forest habitats elevated above the river water surface |
| 10 | <i>Salix</i> species (other than <i>S. gracilistyla</i>) dominant vegetation | Wet forest habitats near the river line in middle and lower stream areas |
| 11 | Annual plant vegetation just beside river channel | Frequently flooded and submerged habitats along the river line |
| 12 | Low-moor vegetation | Wetland habitats around indentations and swamps with low flow velocity |
| 13 | Rudaceous grassland vegetation | Typically dry but infrequently flooded habitats elevated above the river water surface |
| 14 | Floodplain grassland vegetation | Rarely flooded habitats far from and elevated above the river line |
| 15 | Floodplain woody plant vegetation | Floodplain habitats less frequently disturbed than low-moor vegetation |
| 16 | Hill forest vegetation | Rarely flooded hilly habitats |
| 17 | Roadside weed vegetation | Dry and treaded habitats |

government were used for patch identification. After the creation of the vegetation patch map, extensive field surveys using the Braun–Blanquet approach (i.e., phytosociological surveys) were conducted to classify the types of vegetation within the patches (Hyogo Prefecture 2002, 2007). Because surveying all vegetation patches would be prohibitively time-consuming, the phytosociological surveys were conducted on arbitrarily selected patches for each vegetation type. The data set first classified vegetation patches into 17 types based on habitat types that were estimated from dominant species and their life form (Table 1). In addition, land use and unvegetated areas (e.g., natural bare ground, open water, and artificial areas) were also classified into five types, and the vegetation/land-use types were summarised as patches on a vegetation map (Fig. 2). Vegetation was mainly distributed within 50-m of the river line, and each vegetation patch was entered as digital polygon data into GIS (ArcGIS version 9.1; ESRI Co., Tokyo, Japan).

In this study, we used the 17 vegetation types to evaluate habitat heterogeneity, as this vegetation classification system was intended to categorise habitats for plants along river lines of Hyogo Prefecture (Hyogo Prefecture 2009; Table 1).

Data Preparation

We used GIS software (ArcGIS) to divide river lines into 500-m units along all rivers of Hyogo Prefecture; each 500-m unit was a 500-m long and approximately 400-m wide polygon (Fig. 2). The first 500-m unit was placed at the mouth of each river, and the other 500-m units were then set

automatically along river lines starting from the first unit using GIS. When a single vegetation patch was encompassed by two 500-m units, the patch was divided into two 500-m units. We defined a 500-m unit adjacent to more than three other units and including a river confluence as a “confluence unit”, whereas a 500-m unit adjacent to two or fewer other units and not including a river confluence was considered a “single-flow unit” (Fig. 2). A total of 190 units were classified as confluence units, and 1293 units were classified as single-flow units. We also calculated the area of all patches of vegetation within each 500-m unit. We then calculated Shannon (H') and Simpson (D) diversity indices of vegetation patches for each unit as follows:

$$H'_x = -\sum_{i=1}^N (a_i / A_x) \ln(a_i / A_x),$$

$$D_x = 1 - \sum_{i=1}^N (a_i / A_x)^2,$$

where N is the number of vegetation types within the unit x , A_x is the total vegetation area of the unit, and a_i is the area of vegetation i . Finally, we calculated the total vegetation area and stream power index (SPI) per unit. SPI is the product of river-bed inclination and basin area and is generally used as an index of the erosive power of flowing water (Wilson & Gallant 2000). These two factors may affect vegetation diversity in riparian areas; therefore, we incorporated them into the models to control for their effects when determining confluence effects.

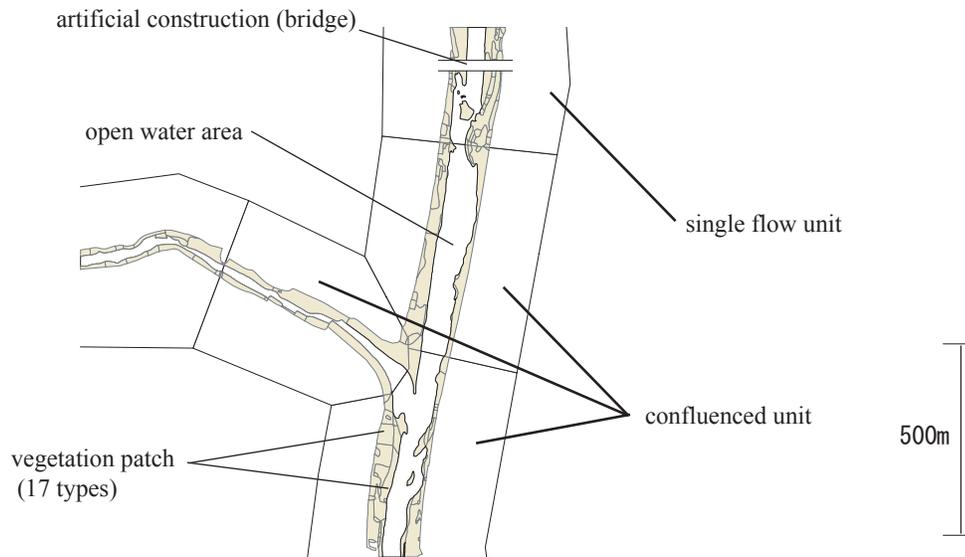


Fig. (2). Example of the Research about the Natural Environment of Rivers (RNER) geographic information system (GIS) data. Square polygons represent individual units. Confluence and single-flow units are defined as units adjacent to more than three other units and two other units, respectively. The central white polygon represents open water, and the other small polygons represent classified vegetation patches.

Pre-Specified Conditions

Data sets for river channel networks have a hierarchical construction: flows compose reaches, which link together to form larger stream networks (Lowe *et al.* 2006). Each of these components has unique traits. In addition, when a

large-scale data set such as the RNER data set is analysed, the power of statistical analyses is often influenced by variation among data collectors, data sampling dates, and non-investigated site characteristics (Link 1999; Link & Sauer 2002; Clark *et al.* 2003; Thogmartin *et al.* 2004). Additionally, environmental factors are usually spatially auto-

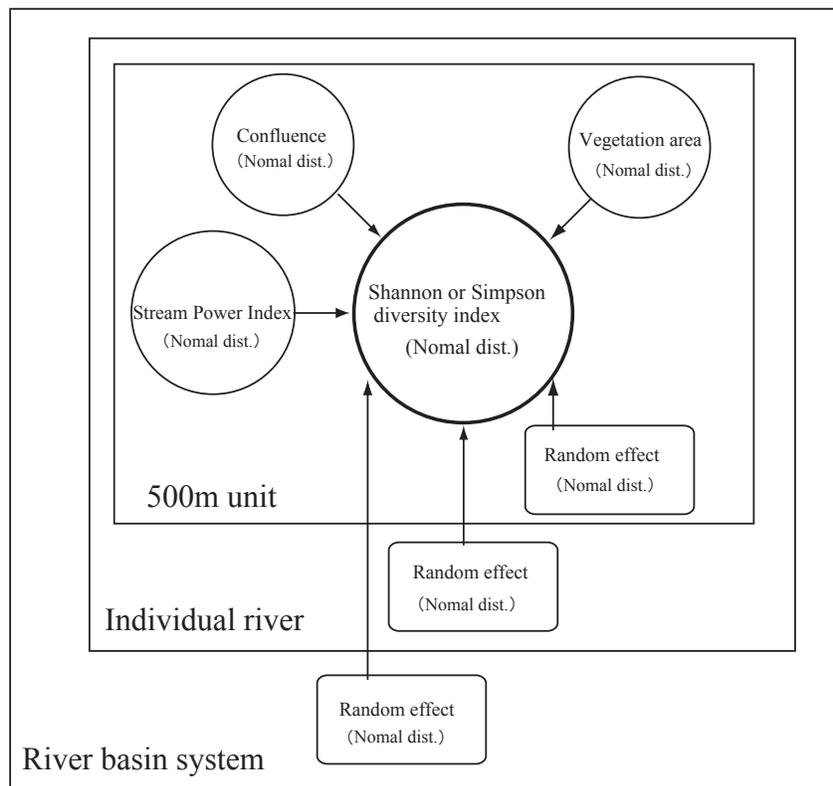


Fig. (3). Conceptual diagram of nested random effect models. The central circle represents the vegetation diversity index (patch number, Shannon H' , or Simpson D'). The surrounding circle represents fix effects, and the wavy square represents random effects.

correlated (e.g., Keitt *et al.* 2002). To minimise these issues, multiple types of random effects should be incorporated into models (Link & Sauer 2002). The use of random effects is an effective method for data summarisation; i.e., the reduction of many parameters into simple summaries (Link 1999). The top-ranked random effect used in our analysis was river basin systems, which are related to variation in river length, catchment area, landform, and other traits. The second-ranked random effect is individual rivers, which are related to the diversity of types and scales of human land use and artificial constructions. The bottom-ranked random effect is individual 500-m units, which are related to unobserved micro-environmental factors such as observer error. Our models incorporated a nested structure of these three random effects, which were treated as mean zero normal random variables (Fig. 3).

Model Establishment

We established hierarchical Bayesian models that included three hierarchical random effects. Shannon H' and Simpson D' were assumed to have normal distributions. Our models can be expressed as:

$$Y_{ijk} \sim \text{Normal}(\alpha_k, V),$$

$$\alpha_k = \text{Intercept} + \text{conf}_k + \text{SPI}_k + \text{area}_k + R_i + R_j + R_k, \text{ and}$$

$$V = \text{Variance of each diversity index},$$

where Y_{ijk} is Shannon H' or Simpson D' in a 500-m unit k on river j of river system i . We used the effects of three physical parameters as fixed effects: the presence of a river confluence (conf , 1, or 0); stream power index (SPI); and total vegetation area (area) of a unit. We also incorporated three random effects: river system, individual river, and individual unit (R_i , R_j , and R_k , respectively).

A necessary initial consideration in a Bayesian analysis is that prior distributions for each variable are informed (Link & Sauer 2002; Thogmartin *et al.* 2004). Because we had little empirical support for one distribution over another, our model was based on non-informative priors (Link & Sauer 2002; Thogmartin *et al.* 2004). All prior random and fixed effects were designed to have standard normal distributions (Fig. 3). Although we could not confirmed normality of the two diversity indices in our data set using the Kolmogorov-Smirnov test (Shannon H' , p -value < 0.001; Simpson D' , p -value < 0.001), both indices did not have extreme dispersion (The means \pm SD of H' and D' were 1.09 ± 0.41 and 0.56 ± 0.19 , respectively) and histograms of both indices had one peak around the mean values. Thus, the variance of each prior diversity index distribution (V) was also designed to have a standard normal distribution.

Fitting the Hierarchical Model

To fit the hierarchical models, we used WinBUGS (The BUGS Project 2008) and R version 2.4.1 software (R Development Core Team 2008) with the R2WinBUGS package to conduct a Markov Chain Monte Carlo (MCMC) analysis using Gibbs sampling. To use the MCMC results, the Markov Chain must change from the initial values into a stationary distribution. We conducted MCMC sampling for 100,000 counts and discarded the initial 30,000 as burn-in. In addition, to minimise results affected by the initial values,

we conducted an analysis of three sets of initial values during MCMC sampling. We used R to generate random-sampling initial values and evaluated the contribution of fixed effects using a posterior predictive check based on a 95% confidence interval.

RESULTS

The means (\pm SD) of Shannon H' at confluence and single-flow units were 1.22 ± 0.32 and 1.07 ± 0.41 , respectively, and the means of Simpson D' at confluence and single-flow units were 0.62 ± 0.15 and 0.52 ± 0.20 , respectively. The mean values of SPI at confluence and single-flow units were 931.57 ± 808.00 and 631.11 ± 705.49 , respectively. The mean areas of vegetation in confluence and single-flow units were $103,106.8 \pm 53,742.2 \text{ m}^2$ and $90,994.7 \pm 62,312.0 \text{ m}^2$, respectively.

Our hierarchical Bayesian-model analysis revealed that all fixed effects had significant positive effects on Shannon H' (the 95% confidence interval did not include 0; Table 2). Simpson D' was positively affected by the presence of a confluence and area of vegetation but was not significantly affected by SPI (the 95% confidence interval included 0 for SPI; Table 3).

Table 2. Quantiles (2.5%, 50%, and 97.5%) of Posterior Distributions of Shannon Diversity Index (H')

| Parameter | Mean | S.D | Values for the Following Percentiles | | |
|-----------------|-----------------------|-----------------------|--------------------------------------|-----------------------|-----------------------|
| | | | 2.5% | 50% | 97.5% |
| Confluence | 7.59×10^{-2} | 2.50×10^{-2} | 2.65×10^{-2} | 7.61×10^{-2} | 1.25×10^{-1} |
| SPI | 4.10×10^{-5} | 1.39×10^{-5} | 1.38×10^{-5} | 4.10×10^{-5} | 6.83×10^{-5} |
| Vegetation area | 1.27×10^{-6} | 2.96×10^{-7} | 6.82×10^{-7} | 1.27×10^{-6} | 1.84×10^{-6} |
| Deviance | -4.12×10^2 | 4.83×10^2 | 1.53×10^3 | -3.37×10^2 | 3.04×10^2 |
| Intercept | 2.24×10^0 | 3.54×10^0 | 4.24×10^{-1} | 6.37×10^{-1} | 1.36×10^1 |

Table 3. Quantiles (2.5%, 50%, and 97.5%) of Posterior Distributions of Simpson Diversity Index (D')

| Parameter | Mean | S.D | Values for the following percentiles | | |
|-----------------|-----------------------|-----------------------|--------------------------------------|-----------------------|-----------------------|
| | | | 2.5% | 50% | 97.5% |
| Confluence | 3.33×10^{-2} | 1.27×10^{-2} | 8.20×10^{-3} | 3.33×10^{-2} | 5.85×10^{-2} |
| SPI | 1.32×10^{-5} | 7.05×10^{-6} | -6.62×10^{-7} | 1.32×10^{-5} | 2.71×10^{-5} |
| Vegetation area | 3.97×10^{-7} | 1.53×10^{-7} | 9.59×10^{-8} | 3.98×10^{-7} | 6.94×10^{-7} |
| Deviance | -2.38×10^3 | 2.58×10^2 | -2.93×10^3 | -2.36×10^3 | -1.94×10^3 |
| Intercept | 1.15×10^0 | 1.06×10^1 | 2.55×10^{-1} | 8.82×10^0 | 3.18×10^1 |

DISCUSSION

Our finding that confluence sites exhibited high vegetation-patch diversity in rivers in Hyogo Prefecture is the

first empirical support of the existence of confluence effects related to biological habitat diversity within riparian areas. Both the Shannon and Simpson diversity indices for vegetation patches were higher for confluence units than for single-flow units. Even though our results revealed a diversity pattern for roughly classified vegetation types, this type of pattern still provides a useful basis for investigating and understanding the process by which habitat diversity is maintained in riparian ecosystems.

Channel disturbances are amplified at confluences because these locations are points that accumulate water, sediments, and woody debris (Benda *et al.* 2004a; Benda *et al.* 2004b; Rice *et al.* 2006; Rice *et al.* 2008). Water movement can strongly affect the distribution of vegetation types throughout floodplains, as such forces alter the physical structure and stability of the habitat through erosion and sedimentation (Salo *et al.* 1986). Debris flows and sediment deposits result in topographic heterogeneity around river confluences (Benda *et al.* 2004b). Together with our results, these findings suggest that habitat diversity increases around river confluences because these areas have unique hydrodynamic features and subsequently amplify disturbance regimes. High habitat diversity generally corresponds to high diversity in plant species (Wagner *et al.* 2000). In fact, we found that plant species diversity was enhanced by the flooding-induced creation of bare ground around confluences of the river system in this study (Osawa *et al.* 2010). In turn, high plant diversity provides diverse habitats and food sources for animals (Qian & Ricklefs 2008). Thus, the highly diverse vegetation patches around river confluences may harbour many plant and animal species in river ecosystems. Future research should examine the detailed processes by which debris and sediment deposition and flooding disturbances enhance the establishment of diverse vegetation types and plant species.

In our analyses, we successfully regulated the effects of SPI and vegetation area in the models, and both factors affected vegetation diversity. For example, SPI positively affected the Shannon diversity index. SPI is conventionally used as an index of the erosive power of flowing water (Wilson & Gallant 2000) and can be used as a representation of disturbance intensity. Relatively strong disturbances likely occurred in high SPI areas, forming various types of vegetation patches, which points to the importance of

disturbance for habitat diversity. Vegetation area positively affected both the Shannon and Simpson indices. The RNER program was conducted throughout alluvial (from mid to downstream) river areas that were surrounded by mainly urban and/or agricultural areas (Hyogo Prefecture 2007). One possible explanation for the positive relationship between diversity indices and vegetation area is that smaller vegetation areas are indicative of the intensification of artificial habitat alterations.

To the best of our knowledge, our study is the first to demonstrate that river confluences may generate habitat diversity for plants in riparian areas, although the results should be interpreted with a little caution because of the failure of our data to meet some assumptions concerning normality of the diversity indices in the analyses. A linear perspective on river networks (i.e., the river continuum concept; Vannote *et al.* 1980) has dominated much of river ecology over the last 20 years (Fisher 1997), despite the recognition that river networks are branched with tributaries that interrupt gradual downstream changes in channel and valley morphology (Benda *et al.* 2004a). Recently, the network dynamics hypothesis has articulated the relationships among key attributes of river networks and the patchy heterogeneity of the fluvial process and form (Benda *et al.* 2004a; Benda *et al.* 2004b). Our results present empirical evidence of this more recent discontinuum perspective in river ecology, in which river confluences are considered key elements within a dendritic river network. Future research should examine confluence effects in a diversity of freshwater riverine systems (e.g. Fernandes *et al.* 2004), with particular focus on the fact that confluences vary in geomorphic features, such as shape and scale, within and among watersheds. Such variation in geomorphic features may produce different confluence effects on biodiversity (Benda *et al.* 2004b).

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Appendix

Appendix 1. List of Communities that Belong to each Vegetation Type in the RNER Data Set. All Scientific Names are Referred to YList, (http://bean.bio.chiba-u.jp/bgplants/ylist_main.html)

| Vegetation type | Community name |
|--|--|
| <i>Miscanthus sacchariflorus</i> dominant vegetation | <i>Miscanthus sacchariflorus</i> community |
| <i>Phragmites communis</i> dominant vegetation | <i>Phragmites australis</i> community |
| <i>Phragmites japonica</i> dominant vegetation | <i>Phragmites japonica</i> community |
| <i>Salix gracilistyla</i> dominant vegetation | <i>Salix gracilistyla</i> community |

(Appendix 1) Contd.....

| Vegetation type | Community name |
|--|--|
| Floating-leaved and submerged plant vegetation | <i>Nymphoides peltata</i> community |
| | <i>Nymphoides indica</i> community |
| | <i>Potamogeton wrightii</i> community |
| | <i>Trapa japonica</i> community |
| | <i>Nuphar subintegerrima</i> community |
| | <i>Potamogeton octandrus</i> community |
| | <i>Potamogeton crispus</i> community |
| | <i>Hydrilla verticillata</i> community |
| | <i>Vallisneria natans</i> community |
| | <i>Potamogeton maackianus</i> community |
| | <i>Ranunculus nipponicus</i> community |
| | <i>Myriophyllum spicatum</i> community |
| | <i>Potamogeton oxyphyllus</i> community |
| | <i>Spirodela polyrhiza</i> and <i>Lemna aoukikusa</i> community |
| | <i>Egeria densa</i> and <i>Elodea nuttallii</i> community |
| | <i>Myriophyllum aquaticum</i> community |
| | <i>Pistia stratiotes</i> community |
| <i>Eichhornia crassipes</i> community | |
| <i>Azolla</i> spp.(exotic) community | |
| Halophytic plant vegetation | <i>Phacelurus latifolius</i> community |
| | <i>Aster tripolium</i> community |
| | <i>Carex scabrifolia</i> community |
| | <i>Limonium tetragonum</i> community |
| | <i>Suaeda australis</i> and <i>Atriplex gmelinii</i> community |
| <i>Artemisia fukudo</i> community | |
| Sand dune vegetation | <i>Carex pumila</i> community |
| | <i>Carex kobomugi</i> and <i>Wedelia prostrata</i> community |
| | <i>Scutellaria strigillosa</i> community |
| | <i>Calystegia soldanella</i> and <i>Lathyrus japonicus</i> community |
| | <i>Vitex rotundifolia</i> community |
| Vegetation beside mountain stream | <i>Hosta montana</i> community |
| | <i>Carex blepharicarpa</i> and <i>Osmunda lancea</i> community |
| | <i>Acorus gramineus</i> community |
| | <i>Carex curvicolis</i> and <i>Sedum subtile</i> community |
| | <i>Carex teinogyne</i> community |
| | <i>Carex persistens</i> community |
| | <i>Carex forficula</i> community |
| <i>Carex heterolepis</i> community | |
| Riparian forest vegetation | <i>Ulmus parvifolia</i> community |
| | <i>Celtis sinensis</i> and <i>Aphananthe aspera</i> community |

(Appendix 1) Contd.....

| Vegetation type | Community name |
|---|---|
| Riparian forest vegetation | <i>Juglans mandshurica</i> community |
| | <i>Melia azedarach</i> community |
| | <i>Zelkova serrata</i> and <i>Acer palmatum</i> community |
| | <i>Euptelea polyandra</i> community |
| | <i>Alnus japonica</i> community |
| <i>Salix</i> species dominant vegetation | <i>Salix chaenomeloides</i> and <i>Salix eriocarpa</i> community |
| | <i>Salix pierotii</i> community |
| | <i>Salix udensis</i> community |
| | <i>Salix miyabeana</i> community |
| | <i>Salix jessoensis</i> community |
| | <i>Salix triandra</i> community |
| Annual plant vegetation just beside river channel | <i>Lindernia procumbens</i> community |
| | <i>Persicaria lapathifolia</i> and <i>Panicum dichotomiflorum</i> community |
| | <i>Microstegium vimineum</i> community |
| | <i>Persicaria thunbergii</i> community |
| | <i>Persicaria hydropiper</i> community |
| | <i>Xanthium occidentale</i> and <i>Chenopodium ficifolium</i> community |
| | <i>Bidens pilosa</i> community |
| Low-moor vegetation | <i>Leersia japonica</i> community |
| | <i>Carex thunbergii</i> and <i>Isachne globosa</i> community |
| | <i>Leersia oryzoides</i> community |
| | <i>Eleocharis mamillata</i> community |
| | <i>Carex dispalata</i> community |
| | <i>Typha latifolia</i> and <i>Typha domingensis</i> community |
| | <i>Ischaemum aristatum</i> community |
| | <i>Phalaris arundinacea</i> and <i>Oenanthe javanica</i> community |
| | <i>Eleocharis kuroguwai</i> community |
| | <i>Leersia sayanuka</i> community |
| | <i>Schoenoplectus triqueter</i> community |
| | <i>Coix lacryma-jobi</i> community |
| | <i>Acorus calamus</i> community |
| | <i>Lycopus lucidus</i> community |
| | <i>Persicaria japonica</i> community |
| | <i>Penthorum chinense</i> community |
| | <i>Sparganium japonicum</i> community |
| | <i>Schoenoplectus tabernaemontani</i> community |
| | <i>Zizania latifolia</i> and <i>Bolboschoenus fluviatilis</i> community |
| | <i>Sparganium erectum</i> community |
| <i>Lythrum anceps</i> community | |

(Appendix 1) Contd.....

| Vegetation type | Community name |
|---------------------------------------|---|
| Low-moor vegetation | <i>Nasturtium officinale</i> community |
| | <i>Paspalum distichum</i> community |
| | <i>Iris pseudacorus</i> community |
| | <i>Alternanthera philoxeroides</i> community |
| | <i>Gymnocoronis spilanthoides</i> community |
| | <i>Cyperus eragrostis</i> community |
| | <i>Stachys aspera</i> community |
| | <i>Humulus scandens</i> and <i>Lactuca indica</i> community |
| | <i>Matteuccia struthiopteris</i> community |
| | <i>Phragmites vallatoria</i> community |
| | <i>Sambucus chinensis</i> community |
| | <i>Arundo donax</i> community |
| | Rudaceous grassland |
| <i>Potentilla chinensis</i> community | |
| <i>Artemisia capillaris</i> community | |
| Grassland vegetation on flood channel | <i>Fallopia japonica</i> community |
| | <i>Boehmeria nivea</i> community |
| | <i>Rumex japonicus</i> community |
| | <i>Miscanthus sinensis</i> community |
| | <i>Imperata cylindrica</i> and <i>Erigeron annuus</i> community |
| | <i>Glycine max</i> community |
| | <i>Arundinella hirta</i> community |
| | <i>Heracleum sphondylium</i> community |
| | <i>Digitaria ciliaris</i> community |
| | <i>Cayratia japonica</i> community |
| | <i>Boehmeria japonica</i> community |
| | <i>Artemisia indica</i> community |
| | <i>Sicyos angulatus</i> community |
| | <i>Verbena brasiliensis</i> community |
| | <i>Conyza sumatrensis</i> community |
| | <i>Artemisia indica</i> community |
| | <i>Coreopsis lanceolata</i> community |
| | <i>Ambrosia trifida</i> community |
| | <i>Festuca arundinacea</i> community |
| | <i>Helianthus tuberosus</i> community |
| | <i>Eragrostis curvula</i> community |
| | <i>Paspalum dilatatum</i> community |
| | <i>Fagopyrum dibotrys</i> community |
| | <i>Solidago altissima</i> community |
| <i>Sorghum halepense</i> community | |
| <i>Lolium multiflorum</i> community | |

(Appendix 1) Contd.....

| Vegetation type | Community name |
|---------------------------------------|--|
| Grassland vegetation on flood channel | <i>Crassocephalum crepidioides</i> community |
| | <i>Ipomoea triloba</i> community |
| | <i>Andropogon virginicus</i> community |
| Floodplain woody plant vegetation | <i>Deutzia crenata</i> community |
| | <i>Lycium chinense</i> community |
| | <i>Aralia elata</i> and <i>Rubus hirsutus</i> community |
| | <i>Rosa multiflora</i> community |
| | <i>Sasa palmata</i> community |
| | <i>Pleioblastus argenteostriatus</i> and <i>Pleioblastus shibuyanensis</i> community |
| | <i>Pleioblastus simonii</i> community |
| | <i>Pueraria lobata</i> community |
| Hill forest | <i>Ampelopsis glandulosa</i> community |
| | <i>Quercus acutissima</i> community |
| | <i>Quercus serrata</i> and <i>Quercus variabilis</i> community |
| | <i>Quercus aliena</i> community |
| | <i>Quercus glauca</i> community |
| | <i>Quercus phillyraeoides</i> community |
| | <i>Castanopsis cuspidata</i> and <i>Photinia glabra</i> community |
| | <i>Quercus myrsinifolia</i> community |
| Roadside weed vegetation | <i>Castanopsis sieboldii</i> community |
| | <i>Digitaria violascens</i> and <i>Eleusine indica</i> community |
| | <i>Eragrostis ferruginea</i> community |
| | <i>Cynodon dactylon</i> community |
| | <i>Pennisetum alopecuroides</i> community |

REFERENCES

- Benda, L, Andras, K, Miller, D & Bigelow P (2004a) Confluence effects in rivers: Interactions of basin scale, network geometry, and disturbance regimes. *Water Resource Research*, 40, W05402.1-15.
- Benda, L, Poff, NL, Miller, D, Dunne, T, Reeves, G, Pess, G & Pollock, M (2004b) The network dynamics hypothesis: How channel networks structure riverine habitats. *Bioscience*, 54, 413-27.
- Burkart, M (2001) River corridor plants (Stromtalpflanzen) in Central European lowland: a review of a poorly understood plant distribution pattern. *Global Ecology and Biogeography*, 10, 449-68.
- Clark, JS, Mohan J, Dietze, M & Ibanez, I (2003) Coexistence: How to identify trophic trade-offs. *Ecology*, 84, 17-31.
- De Serres, B, Roy, AG, Biron, PM & Best, JL (1999) Three-dimensional structure of flow at a confluence of river channels with discordant beds. *Geomorphology*, 26, 313-35.
- Fernandes, CC, Podos, J & Lundberg, JG (2004) Amazonian ecology: Tributaries enhance the diversity of electric fishes. *Science*, 305, 1960-62.
- Fisher, SG (1997) Creativity, idea generation, and the functional morphology of streams. *Journal of the North American Benthological Society*, 16, 305-18.
- Grant, EHC, Lowe, WH & Fagan, WF (2007) Living in the branches: population dynamics and ecological processes in dendritic networks. *Ecology Letters*, 10, 165-75.
- Haddad, NM, Holyoak M, Mata, TM, Davies, KF, Melbourne, BA & Preston, K (2008) Species' traits predict the effects of disturbance and productivity on diversity. *Ecology Letters*, 11, 348-56.
- Hyogo Prefecture (2002) Official research manual of Research of Natural Environment of River.
- Hyogo Prefecture (2007) Research of Natural Environment of River, Atlas.
- Hyogo Prefecture (2009) A guideline for riparian vegetation classification in Hyogo Prefecture, improved edition.
- Keitt TH, Bjornstad ON, Dixon, PM & Citron-Pousty, S (2002) Accounting for spatial pattern when modeling organism-environment interactions. *Ecography*, 25, 616-25.
- Knick, ST, Rotenberry, JT & Leu, M (2008) Habitat, topographical, and geographical components structuring shrubsteppe bird communities. *Ecography*, 31, 389-400.
- Link, WA (1999) Modeling pattern in collections of parameters. *The Journal of Wildlife Management*, 1017-27.
- Link, WA & Sauer, JR (2002) A hierarchical analysis of population change with application to Cerulean Warblers. *Ecology*, 83, 2832-40.
- Lowe, WH, Likens, GE & Power, ME (2006) Linking scales in stream ecology. *Bioscience*, 56, 591-97.
- May, RM (2006) Network structure and the biology of populations. *Trends in Ecology & Evolution*, 21, 394-99.
- Montoya, JM, Pimm SL & Sol, RV (2006) Ecological networks and their fragility. *Nature*, 442, 259-64.
- Naiman, RJ, Decamps, H & Pollock, M (1993) The Role of Riparian Corridors in Maintaining Resional Biodiversity. *Ecological Applications*, 3, 209-12.
- Osawa, T, Mitsuhashi, H & Ushimaru, A (2010) River confluences enhance riparian plant species diversity. *Plant Ecology*, in press.
- Qian, H & Ricklefs, RE (2008) Global concordance in diversity patterns of vascular plants and terrestrial vertebrates. *Ecology Letters*, 11, 547-53.

- R Development Core Team (2008) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: <http://developer.r-project.org/>
- Rhoads, BL & Kenworthy, ST (1995) Flow structure at an asymmetrical stream confluence. *Geomorphology*, 11, 273-93.
- Rice, SP, Ferguson, RI, & Hoey, TB (2006) Tributary control of physical heterogeneity and biological diversity at river confluences. *Canadian Journal of Fisheries and Aquatic Sciences*, 63, 2553-66.
- Rice, SP, Roy AG & Rhoads BL (2008) *River confluences, tributaries & the fluvial network*. Wiley inc.
- Salo, J, Kalliola, R, Hakkinen I, Makinen, Y, Niemela, P, Puhakka, M & Coley, PD (1986) River dynamics and the diversity of Amazon lowland forest. *Nature*, 322, 254-58.
- Svensson, JR, Lindegarh, M, Siccha, M, Lenz, M, Molis, M, Wahl, M & Pavia, H (2007) Maximum species richness at intermediate frequencies of disturbance: Consistency among levels of productivity. *Ecology*, 88, 830-38.
- The BUGS Project (2008) URL: <http://www.mrc-bsu.cam.ac.uk/bugs/>
- Thogmartin, WE, Sauer, JR & Knutson, MG (2004) A hierarchical spatial model of avian abundance with application to Cerulean Warblers. *Ecological Applications*, 14, 1766-79.
- Vannote, RL, Minshall, GW, Cummins, KW, Sedell, JR & Cushing, CE (1980) The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences*, 37, 130-37.
- Wagner, HH, Wildi, O & Ewald, KC (2000) Additive partitioning of plant species diversity in an agricultural mosaic landscape. *Landscape Ecology*, 15, 219-27.
- Wilson, JP & Gallant JC (2000) *Terrin Analysis-Principle and Applications*. New York: John Wiley and Sons, inc.

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