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Roles of disturbance in structuring geomorphology for riverine animal communities

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ABSTRACT: Local species diversity is maximized when ecological disturbance is the intermediate disturbance. However, artificial impacts such as dam, excavation and levee caused decreasing dynamism and activity of sediment and biological habitats, and thereby biodiversity by disturbance less than intermediate. This paper aims at showing the effects of decreasing disturbance on changes of landscapes and geomorphic habitat diversity. Hierarchical structure of aquatic habitats in the lower reaches of the Kizu River, a tributary of the Yodo River, central Japan, was investigated using the aerial photos taken in 1948, 1961, 1971, mid 70 s, 1979, 1990, 2002, 2008, 2010 and 2012. Results of the landscape changes showed that water surface and bareland significantly decreased with increasing bushland and woodland. Average channel width, braided index and shoreline index as geomorphic parameter decreased gradually. According to changes of landscapes and geomorphic parameters, habitat diversity increased gradually between 1948 and 2012. Increase of habitat diversity during the period indicated that the increase of vegetation area contributed to raising habitat diversity to some extent. Therefore, vegetation expansion derived from stabilization of flow regimes and reduction in sediment dynamics fascinated the environmental heterogenety in there 60 years in the Kizu River.

1 INTRODUCTION

Artificial impacts such as dam, excavation and weir caused blocking the upstream sediment supply and fundamental fluvial hydrology (Williams and Wolman, 1984; Grant et al., 2003). Thus, rivers lost biological dynamism and continuity of the upper and lower sides by decrease of disturbance.

The intermediate disturbance hypothesis states that local species diversity is maximized when ecological disturbance is neither too rare nor too frequent (Connell, 1978). This hypothesis suggests that maximum diversity is found at intermediate levels of natural disturbance.

This paper aims to show the effects of decreasing disturbance on changes of landscapes and geomorphic parameters with habitat diversity by aerial photos in the Kizu River.

Habitat diversity is useful predictor of species diversity, because the number of habitats in a region is almost always positively correlated with the number of species inhabiting (Joaquin et al., 2009).

2 STUDY SITE

The study area was established in the lower reaches (0~26 km) of the Kizu River, a tributary of the Yodo River in central Japan.

Sediment and discharge of the Kizu River were influenced by 5 dams; Takayama Dam (1969), Syourenzi Dam (1970), Murou Dam (1974), Nunome Dam (1992), Hinachi Dam (1999) (Fig. 1). Sediment supply and discharges decreased and riverbed degraded after construction of dams and sand excavation from 1958 to 1963.

The Kizu River has been so called as a typical sand river, because it is strongly influenced by granite in upper stream of Kizu River basin. In 1965, an estimated 100,578 m^3/y of sediment discharge decreased about 80% in 2010 (Fig. 2). The average of annual peak discharges after construction of Takayama Dam (1970) also decreased (Fig. 3).The riverbed of the Kizu River had degraded from minimum 0.8 m to maximum 4.9 m with decrease of sediment discharge and

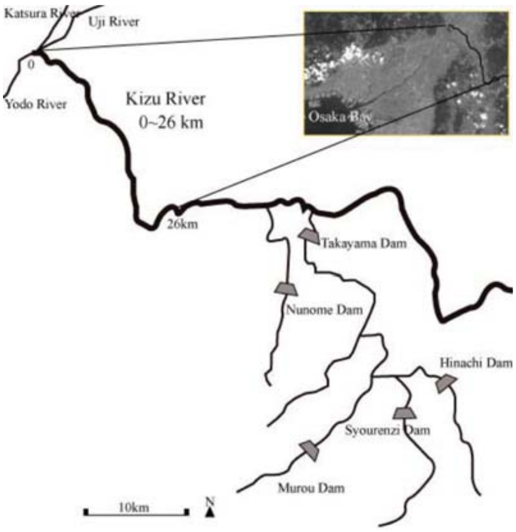

Figure 1. A map of the Kizu River basin.

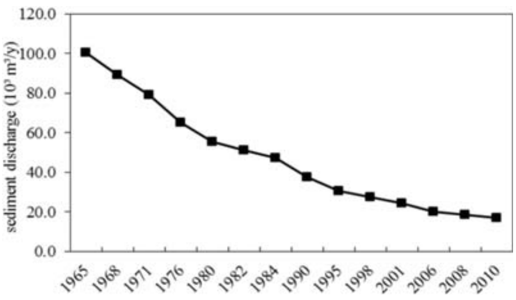

Figure 2. Changes of sediment discharge between 1965 and 2010 (Yodogawa River Breau, 2012).

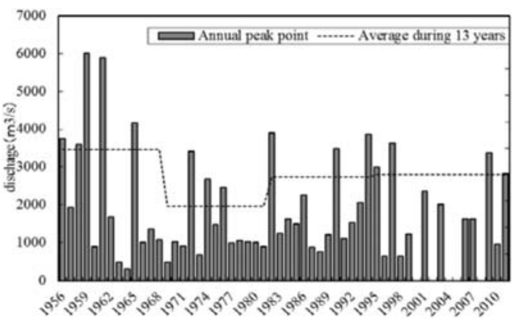

Figure 3. Annual peak discharge in Inooka observatory from 1956 to 2012. The average annual peak discharge calculated per 13 years. Average value between 1956 and 1968 is value before construction of Takayama Dam (Yodogawa River Breau, 2012).

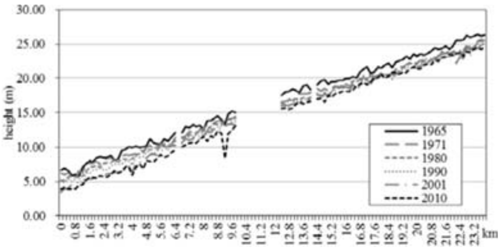

Figure 4. The riverbed degradation of the Kizu River 0~23.2 km between 1965 to 2012 (Yodogawa River Breau, 2012).

annual peak discharges during about 60 years (Fig. 4). Floodplain is dominated by vegetation and stabilized with reduction of channel width (Fig. 6).

3 METHODS

To examine longer term patterns of riverbed geomorphology on the Kizu River, the orthorectified and georeferenced aerial photographs that comprise information on terrain topography and x-y coordinate have been collected among usable data from the Yodogawa River Bureau. We compiled sequential aerial photos from 1948, 1961, 1971, mid 70 s (1974~1978), 1979, 1990, 2002, 2008, 2010 and 2013. In order to minimize errors, all data overlaid according to coordinate and quantitatively calculated area of landscapes and habitats using ArcGIS (ESRI). All parameters calculated and classified per 1 km unit.

3.1 *Landscape parameters*

Landscape parameter was classified into water surface, bareland, bushland, woodland, cleared-land. Cleared-land was defined as using land (e.g., farm, playground and bamboo forest) or empty space by tree cutting.

3.2 *Geomorphic parameters*

Channel width was estimated by the average width of active channel (low flow channel and islandbars) by transects spaced 250 m apart in 1 km unit. Braided index was calculated as total channel length (sum of mid-channel lengths of all channels, divided by length of the widest channel's mid-line; Friend and Sinha, 1993). Shoreline index was determined as value of total aquatic area (water surface in channel and aquatic habitat on the floodplain) to total length of shoreline. Shoreline index is important for ecology since it reflects the amount of shallow and low velocity habitats (Bowen et al., 2003) for many riverine species including softshell turtles (Plummer, 1997; Moll and Moll, 2004), riverine fishes (Scheidegger and Bain, 1995; Johnson and Jennings, 1998).

3.3 *Aquatic habitat*

Aquatic habitat was classified into lotic and lentic ecosystem depending on spatial size of animals and their home rages. As guided by the classification criteria in Table 1, Aquatic habitat type composed lotic (riffle, deep-slow) and lentic (bar-head wando, bar-tail wando, active pond, terrace pond). Deep-slow does not show in this study, because it was difficult to calculate the number (it was estimated total area of water surface in main channel except riffle.).

Habitat diversity was estimated as richness index and diversity index. Habitat richness was defined as total number of aquatic habitats; riffle, bar-head wando, bar-tail wando, active pond, terrace pond. According to definition of habitat richness, it has value from minimum 0 to maximum 5.

Habitat diversity was calculated by Shannon-Wiener index.

$$\text{Diversity} = -\sum_{i=1}^{R} p_i \log p_i$$

R = richness, p_i = proportional abundance of the ith type.

Table 1. Definitions of classification of aquatic habitat based on aerial photographs in the Kizu River.

Habitat type	Definition
Lotic	
Riffle (RF)	Area of high current flow with rough water surface rowing locating point of bars
Deep-Slow (DF)	Area of slow deep flow with smooth water surface locating between riffles
Lentic	
Bar-Head Wando (HW)	Channel blocked by bare/vegetation deposits with upstream connection
Bar-Tail Wando (TW)	Channel blocked by bare/vegetation deposits with downstream connection
Active Pond (AP)	Side pool in active channel Permanent or temporary standing stagnant water on bare land
Terrace Pond (TP)	Side pool on terrace at abandoned channel Permanent or temporary standing stagnant water on wood/bush land

3.4 *Statistical analysis*

Annualized rates of change in channel were compared using a one-way ANOVA. Correlation analysis and regression analysis was used to examine relations of habitat diversity to landscape and geomorphology.

4 RESULTS

4.1 *Landscape*

Landscape in the lower reaches of Kizu River showed significant changes between 1948 and 2012. Aerial photo showed marks of sand excavation in 1961 and woodland developed on floodplain in 1971 (Fig. 5). They probably were reflected by the lack of large floods in preceding years, as well as a corresponding reduction in the frequency of disturbance.

Bareland area decreased about 70% from 1961 to 2008, and increased between 2008 and 2012

Figure 5. Historical changes of the Kizu River landscapes in 3~4 km.

slightly. Although area of water surface decreased gradually since 1948, they increased between 2010 and 2012 (Fig. 6).

The decrease in bareland and water surface resulted from the expansion of vegetation area (bush + wood). Expansion of woodland and bushland marked since 1961 due to sand excavation and construction of Takayama Dam. However, bushland decreased about 20% from 2008 to 2012 and woodland decreased about 28% in 2012 compare to 2010 by management of wood cutting in 2011 and 2012.

4.2 *Geomorphic parameters*

By 1948, the active channel had narrowed by the accretion of islands and stabilization of mobile bars. Average channel width significantly decreased from 170.6 m in 1948 to 97.7 m in 2012. Increase of channel width in 2012 was reflected by detachment of bareland from floodplain (Fig. 7.a). Braided index decreased gradually from 2.23 in 1948 to 1.39 in 2012 (Fig. 7.b). Shoreline also decreased gradually from 31.3 in 1948 to 18.4 in 2012 (Fig. 7.c). Decrease of shoreline index in 2010 resulted of increase of the area of water surface and disappearance of multiple channels.

4.3 *Aquatic habitat*

The Number of RF decreased about 50% from 113 in 1948 to 54 in 2012, in spite of increase between 1961 and mid 40'. The number of HW remained between 7 and 20 without significant changes since 1961. The number of TW increased gradually from 12 to 39 during about 60 years. The number of AP decreased until 2002 and increased between 2002 and 2010. The number of TP increased from 1948 to 2012, especially between 2008 and 2012. The number of TW and TP among 5 habitat type only increased gradually during about 60 years (Fig. 8).

Habitat richness and diversity showed similar results on the Kizu River. Habitat richness increased from 2.61 to 3.84 and diversity index also increased from 0.73 to 1.12 (Fig. 9).

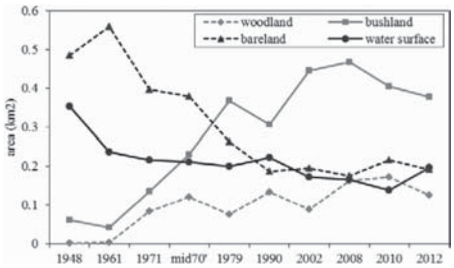

Figure 6. Changes of landscape in the Kizu River between 1948 and 2012.

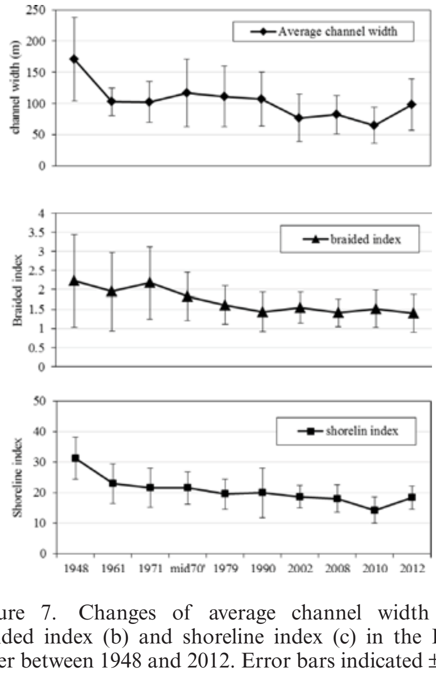

Figure 7. Changes of average channel width (a), braided index (b) and shoreline index (c) in the Kizu River between 1948 and 2012. Error bars indicated ±SD.

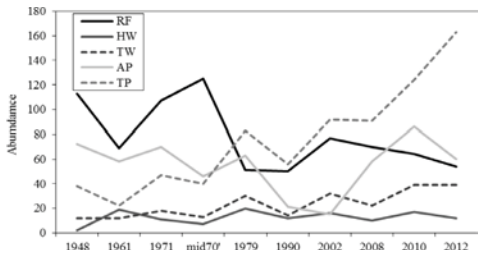

Figure 8. Changes of abundance of aquatic habitat between 1948 and 2012. Abundance represents total number of the habitats in 26 km reaches.

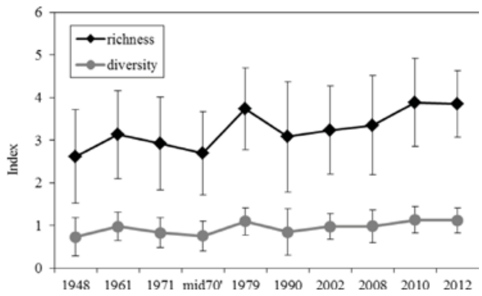

Figure 9. Changes of habitat richness and diversity index between 1948 and 2012. Error bars indicated ±SD.

5 DISCUSSION

5.1 *Relations of habitat to landscape and geomorphology*

Number of riffle was positively correlated high geomorphic parameters (e.g., channel width, braided index) than landscapes. This result showed number of riffle decreased with decreasing channel width and braided index in the Kizu River (Fig. 10.a).

Number of HW was not significantly correlated with changes of landscapes and geomorphic parameters. The ratio of vegetation (bushland + woodland) in channel showed positive correlation with TW and TP, and negative with AP (Fig. 10.b, 10.c). This indicated number of TP and TW increased with vegetation expansion. In contrast, AP decreased with vegetation expansion and decrease of bareland (vegetation ratio and bareland ratio have negative correlation. coeffient = –0.83, $P < 0.001$).

Habitat richness and diversity had positive correlation with the ratio of vegetation in channel (richness $r = 0.24$ and $P < 0.001$, diversity $r = 0.16$ and $P = 0.01$) and negative correlation with the ratio of bareland (richness $r = -0.22$ and $P < 0.001$, diversity $r = -0.14$ and $P = 0.01$).

Habitat richness and diversity increased with increase of vegetation similar to TW and TP. This result was explained by Table 2. Correlation with each habitat and habitat diversity showed the highest coefficient with HW and TW. RF and AP distributed most of the reaches, whereas TW and HW low a density. Therefore, habitat richness and diversity will be influenced by existence of TW and HW. In addition, TP were positively influenced by vegetation expansion contributed high habitat diversity.

Habitat diversity had negative correlation or low correlation with RF.

Habitat richness and diversity index showed small difference with vegetation. Habitat richness index had more high correlation with vegetation than diversity. However, Habitat richness and diversity index had high correlations with vegetation than each wood land and bushland (Table 3).

5.2 *Relations of disturbance to geomorphology*

Flow and sediment modification has resulted in the expansion of vegetation and loss of the initial channel width. Since the 1960s, the width of the channel has stabilized, vegetation has trapped sediments, and woodland had developed. Vegetation expansion was related to species diversity lived on vegetation area positively, on the other hand, they caused decreasing discharge capacity and increasing stabilized bars (..).

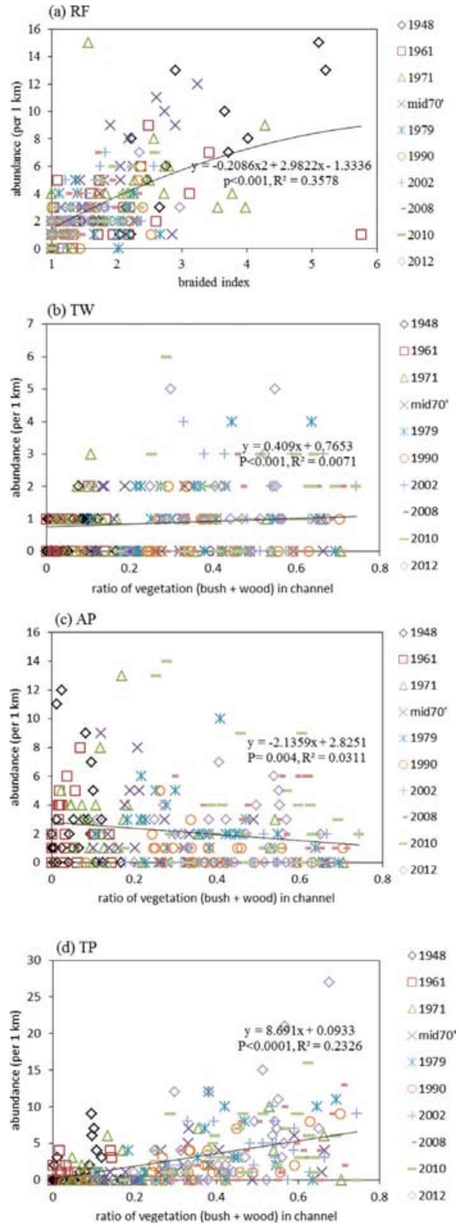

Figure 10. Regression analysis of each abundance of habitat to landscape and geomorphology. Correlation of abundance of (a) RF and braided index (b) TW and vegetation ratio in channel (c) AP and vegetation ratio in channel (b) TP and vegetation ratio in channel.

In this study, the abundance of aquatic habitat and habitat diversity increased with expansion of vegetation. It indicated that the increase of vegetation area contributed to raising habitat diversity to some extent. Therefore, the stability of flow regimes

Table 2. Correlations of habitat richness and diversity index to abundance of habitat.

	Richness		Diversity	
Habitat	*r*	*P*	*r*	*P*
RF	–0.063	0.3	–0.123	0.05
HW	0.505	<0.001	0.447	<0.001
TW	0.539	<0.001	0.515	<0.001
AP	0.291	<0.001	0.231	<0.001
TP	0.312	<0.001	0.128	0.04

Table 3. Correlations of habitat richness and diversity index to vegetation area in channel.

	Richness		Diversity	
Landscape	*r*	*P*	*r*	*P*
Wood	0.209	<0.001	0.136	0.03
Bush	0.216	<0.001	0.144	0.02
Veg (wood + bush)	0.241	<0.001	0.160	0.01

and reduction in sediment dynamics fascinated the environmental heterogenety in there 60 years in the Kizu River.

6 CONCLUSION

In the Kizu River, bareland area decreased about 70% from 1961 to 2008, and bushland area and woodland area significantly increased between 1961 and 2012. The average of channel width and braided index gradually decreased between 1948 and 2010 and shoreline index decreased until 1979. The changes of landscapes and geomorphic parameters were influenced by construction of dams and sand excavation from 1958 to 1963. As aquatic habitat, TP and TW increased with decrease of RF and AP between 1948 and 2012. At a same time, habitat richness and diversity increased gradually. The habitat richness and diversity during the period indicated that the increase of vegetation area contributed to raising habitat diversity to some extent. Although size and frequency of disturbance in the Kizu River had decreased, it influenced positive effect in terms of geomorphic habitat structure.

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