THE HISTORICAL CHANGES OF AQUATIC HABITAT STRUCTURE IN THE KIZU RIVER

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Abstract: Hierarchical structure of aquatic habitats in the lower reaches of the Kizu River, a tributary of the Yodo River, central Japan, was investigated using images of aerial photographs taken in 1948, mid-1970s and 2009. The channel landscapes into water surface, island bar and lateral bar as channel scale characteristics. Bar scale landscapes into bareland, bushland, woodland and cleared-land for artificial land use. And then, aquatic habitats were classified into riffle, run and deep slow, active pool, terrace pool, bar-head backwater and bar-tail backwater. Historical changes in the habitat structure were analyzed quantitatively using the DEM data and the aerial photographs. Results of the landscape changes showed that bar area and shoreline index in the channel scale increased with decreasing water surface, and at the same time, bareland decreased with increasing bushland and woodland. The significant increase of habitat richness during the period indicated that the increase of vegetation area contributed to raising habitat richness to some extent. Therefore, the stability of flow regimes and reduction in sediment dynamics fascinated the environmental heterogenety in there 60 years in the Kizu River.

Keywords: Fluvial geomorphology, landscape, habitat richness, sandy bar, historical change, Kizu River.

1. INTRODUCTION

Habitat diversity is closely related to high biodiversity in terms of most stream animals needed a set of different habitats with stages of their life cycle (Yuma and Hori 1990; Holomuzki and Messier 1993; Takemon 1997). For example, different geomorphic habitat may act as feeding (runs), resting (backwater), and spawning (gravel bars) sites for fish, such that the reach-scale assemblage of geomorphic units may influence the composition of fish assemblages (Brierley and Fryirs, 2005). Since geomorphic units constitute relatively distinct habitats for aquatic fauna and flora, they provide a sound basis with which to link geomorphological structure and ecological habitat (Thomson, 2001).

In general, habitat diversity evaluated spatial patch or mosaic in terms of Landscape ecology (Nathan et al., 2012; Hohensinner et al., 2011). Traditional methods in landscape ecology are based on the assumption that such patches exhibit high levels of within-patch homogeneity, so that measures such as patch size, patch density, and the broader spatial arrangement of patches can be used to assess overall landscape structure and connectivity (Riitters et al.,1995; Gustanfson, 1998).The type number, and connectivity among patch types in these systems is a function of large scale and long-term

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feedbacks among hydrology, geomorphology, ecology, and human land and water use (Ward et al., 1999) and strongly influence biodiversity patterns (Ward et al., 1999; Koel,2004; Thorp et al., 2006). Several studies have classified the habitats based on geomorphic influence (Brierley and Fryirs, 2005; Ro Charlton, 2008; Church, 1992; Schumm, 1977), e.g. pools, riffles, cascades, bar, benches, levees, and cutoff channels, levees, crevasse splays, backswamps, flood channels, floodouts, meander scroll bars, cut-offs, palaeochannels,; fish community (John and Edwin., 2008), e.g. bars, benches, riffle-pool sequences, steps and pools, rapids and cascades, potholes, bedrock bars or matrix type of pool-front, pool-mid, pool-rear, pool-scour, gride, riffle-simple, riffle-complex, submerged point bar, marginal deadwater ; aquatic area (Wilcox 1993; Nathan, 2012) e.g. main navigation channel, main channel border, secondary channel, tertiary channel, tributary channel, contiguous floodplain lake, contiguous floodplain shallow aquatic area, contiguous impounded area, isolated floodplain lake, isolated floodplain.

Prediction of future changes, and understanding how best to return degraded reaches to a good condition will require a functional understanding of how large-scale geomorphic processes operate under various catchment conditions to shape local habitat (Thomson et al., 2001). Within floodplain landscapes, habitat patches can be delineated using standard geomorphologic techniques along with aerial photography (Thoms, 2003; Thorp et al., 2006). The present study investigated the long-term habitat composition and the spatially and temporally varying habitats during a time period by from which generally no detailed data are available.

The intermediate disturbance hypothesis (Connell, 1978) relates biotic community diversity to disturbance frequency and intensity. This hypothesis suggests that maximum diversity is found at intermediate levels of natural disturbance. At high rates of disturbance, only early successional species, which are generally good colonizers but poor competitors, are able to survive. In contrast, the maximum species diversity can be also expected when the habitat diversity becomes the maximum under intermediate disturbance condition (Takemon, 1997). In fact, rivers that migrate across their floodplains form complex channel patterns and contain high diversity of habitat riparian and aquatic habitat types (e.g. Kondolf et al., 2003; Beechie et al., 2006). Thus diversity of aquatic habitat types will be a good indicator for testing the latter hypothesis. This paper aims at showing the relationship among historical changes of landscape characteristic, habitat richness and habitat abundance in the Kizu River.

2. METHOD

2.1. Study Site

The study area was established in the lower reaches (0~26km) of the Kizu River, a tributary of the Yodo River in central Japan (Fig.1). Because it is strongly influenced by grantite in upper stream of Kizu River basin, it had been so called as a typical sand river. A mean of river slope in study area was 1/1180 and mean diameter of bed material was 2 mm ~3 mm.

Channels of the Kizu River had changed dynamically with a huge amount of sediment as a flow from tributaries. However, the riverbed has been degraded and the bars have been fixed due to sand excavation in 1960’s and construction of 5 dams; Takayama Dam (1969), Syourenzi Dam (1970), Murou Dam (1974), Nunome Dam (1992), Hinachi Dam (1999). The flood exceeding 4000 m3/s in discharge decreased and the mean annual maximum discharge become less frequant from 2500 m3/s to 1800 m3/s by Takayama Dam (Kizu River research Group, 2009). Although the Kizu River is under the influence of the excavation and dam construction, the study reaches have various habitat structures in the channel. After started to shows the alternative bars in 1970’s, riverbed of this section has been changed from braided to double row bar.

Fig.1. Study area

2.2. Data sources

In other to analysis how to be changed the number or area of aquatic habitat during period, the rectified aerial photographs that comprise information on terrain topography, x-y coordinate have been collected among usable data from the Yodogawa River Bureau. The selected 3 aerial photo of 1948, 1974~1978 (mid70s), 2009 were used for the study.

2.3. Landscape and habitat classification

In order to minimize errors of survey, recent aerial photograph compared with DEM data and the map of plants altitude in 2009 at first. All data overlaid according to coordinate and quantitatively calculated the number or area of habitats by Acrgis (ESRI). And then, these works were conducted step by step in recent years order with considering color type of each aerial photo with considering photo flight season. Within study area (0~26km), Area and number of habitats classified per 1km unit.

2.3.1. Landscape parameter

Landscape parameter classified channel scale characteristics and bar scale characteristics. Channel scale landscapes were classified into water surface, island bar and lateral bar. The island bar defined as bar area larger than 200m2. Bar scale landscapes were classified into bareland, bushland, woodland, cleared-land. Cleared-land defined as farm or empty space by tree cutting (Fig. 2).

Additionally, shoreline index and sinuosity ratio considered as landscape parameter. Shoreline index have important value in terms of landscape ecology. Water along the shoreline provides shallow, low velocity habitats (Emily et al., 2011; Bowen et al., 2003) that are used by many riverine species including softshell turtles (Plummer, 1997; Moll and Moll, 2004), riverine fishes (Scheidegger and Bain, 1995; Johnson and Jennings, 1998). Shoreline index is calculated as follows:

$$D = \frac{L}{2\sqrt{\pi A}}$$

Where L is the length of the shore, and A is the surface area.

Sinousity ratio was possible to check a tendency of thalweg or degree of curve in channel. Sinousity defined as ratio of channel length to valley length (Charlton, 2008). In this study, sinuosity calculated length of flow channel to straight length per 1km unit.

2.3.2. Aquatic habitat parameter

Habitat parameter classified based on the spatial classification of Habitatology introduced by Takemon (2007). Habitatology is a specialized field of science for analyzing habitat structure and elucidating mechanism of habitat creation and maintenance. This is classified into lotic and lentic ecosystem depending on spatial size of animals and their home rages.

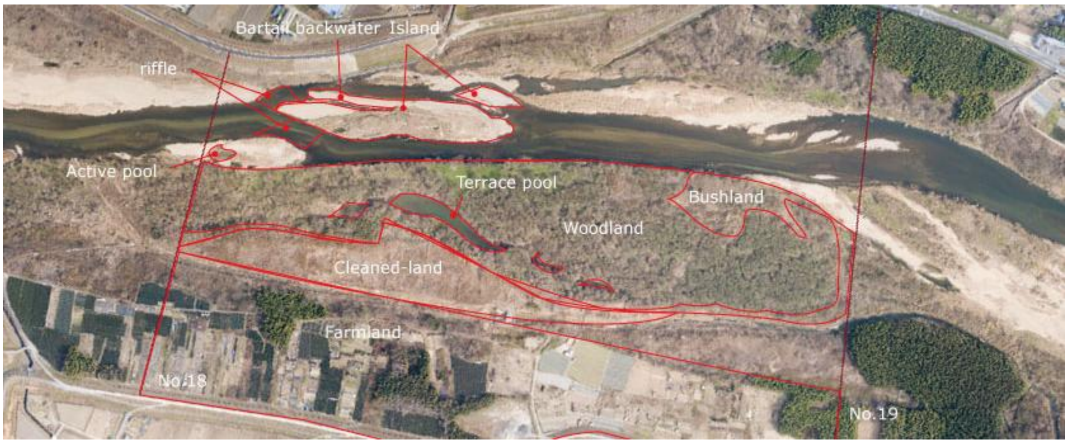


Fig. 2 An example of classification of landscape and habitats in reaches at 18km-19km in the KizuRiver

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

habitat type		definition
lotic	riffle	area of high current flow with rough water surface rowing locating point of bars
lotic	run and deep-slow	area of slow current flow with smooth water surface locating between riffles
lentic	active pool	side pool in active channel permanent or temporary standing stagnant water on bare land
lentic	terrace pool	side pool on terrace at abandoned channel permanent or temporary standing stagnant water on wood/ grassland
lentic	Bar-head backwater	channel blocked by bare/vegetation deposits with upstream connection
lentic	Bar-tail backwater	channel blocked by bare/ vegetation deposits with downstream connection

As guided by the classification criteria in Table. 1, habitat classified within the study area. Aquatic habitat composed riffle, active pool, terrace pool, bar-head backwater, bar-tail backwater (Fig. 2).

3. DATA ANALYSIS

3.1. Landscape characteristic

Area of total habitats was summarized in each year. A one-way ANOVA and paired-sample t-test tested for differences in mean and sum of area, as well as index of shoreline and sinuosity per each year.

3.2. Aquatic habitat characteristic

Total area and number of aquatic habitat was also summarized in each year. Habitat richness defined as total number of aquatic habitats was classified 5 type; riffle, active pool, terrace pool, bar-head backwater, bar-tail backwater. According to definition of habitat richness, it has value from minimum 0 to maximum 5.

Aquatic habitat also was ascertained by analyzing of a one-way ANOVA and t-test.

3.3. Relations of habitat richness and landscape characteristic

To examine relations of habitat richness to landscape characteristic, regression analysis was used. Channel ratio and Lateral bar ratio, shoreline index and sinuosity index selected measured variables among channel scale characteristic and bareland ratio and vegetation-land (bushland + woodland) ratio selected among bar scale characteristic. Correlation between all measured variables and habitat richness showed each relation that they have. Graph showed coefficients of regression with probability line, if they have the relation each other.

4. RESULTS

4.1. Landscape characteristics

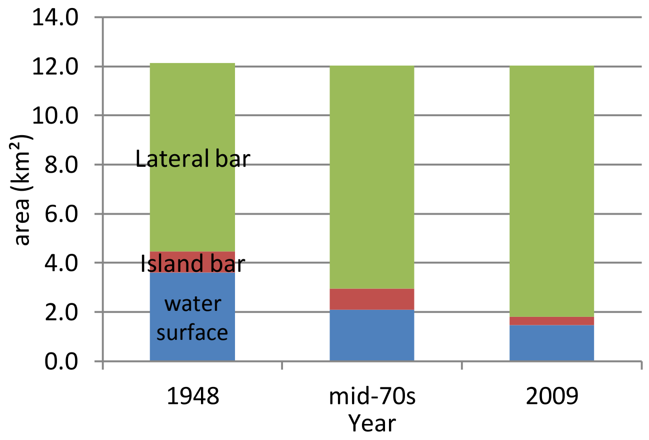
4.1.1 channel scale characteristics

The Kizu River landscape scale was comprised of channels and bars of 2types, island bar and lateral bar. The mean area of the lateral bar differed discernibly among the years from 61.3 in S23, to 74.8 in mid-70s and 85.3 in 2009 ($P<0.00001$, one-way ANOVA)(Fig. 3). The area of lateral bar increased continually during period ($P<0.005$, t-test). The mean island bar area showed 8.0, 7.5 and 2.4 in 1948, mid-70s and 2009, respectively ($P=0.024$, one-way ANOVA). The island bar area were not different between 1948 and 1970 ($P=0.85$, t-test), whereas the value in 2009 was smaller than 1948 and mid-1970s significantly ($P<0.05$, t-test).

The mean channel area was 30.7, 17.7 and 12.3 in 1948, mid-70s and 2009, respectively ($P<0.00001$, one-way ANOVA). The channel area decreased continually ($p<0.00001$, t-test) with increasing the lateral bar area. Shoreline index was 2.92, 3.55 and 3.77 on average in 1948, mid-70s and 2009, respectively ($P=0.01$, one-way ANOVA)(Fig. 4). Value in 1948 was significantly lower than mid-70s, 2009 ($p=0.009$, t-test). Sinousity ratio was 1.07, 1.08 and 1.09 on average in 1948, mid-70s and 2009, respectively ($P=0.5$, one-way ANOVA)(Fig. 5). Sinuosity ratio increased slightly ($p>0.3$, t-test).

4.1.2 Bar scale characteristics

The bars consisted of bareland, bushland, woodland and cleared-land (Fig. 6). Total area of the bareland in bars in 0~26km reaches of the Kizu River was 4.8, 3.8 and 2.3 in 1948, mid-70s, 2009,respectively ($P<0.00001$, one-way ANOVA). The bareland area showed continuous reduction significantly ($p<0.005$, t-test). In contrast to bareland, the area of bushland significantly increased from 1948 to 2009 ($P<0.0001$, t-test). The bushland area was 0.58, 2.38 and 3.96 in 1948, mid-1970s and 2009, respectively ($P<0.00001$ one-way ANOVA).The area of woodland was the smallest in 1948($p<0.00001$, t-test). It differed from 0.12 in 1948 to 1.39 in mid-1970s and 1.95 in 2009 ($P<0.00001$, one-way ANOVA). The cleared-land was 0.11, 0.09 and 0.087 in 1948, mid-1970s and 2009, respectively ($P=0.44$, one-way ANOVA). The cleared-land did not differed significantly ($p>0.01$, t-test).



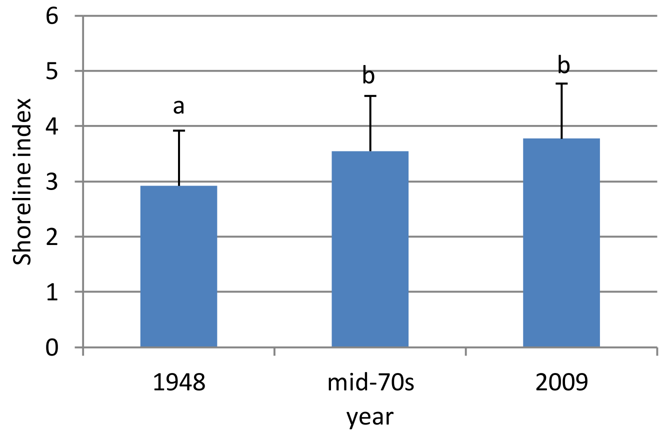
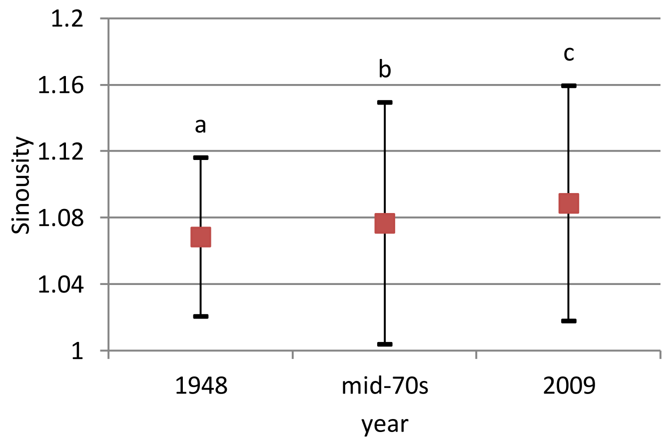


Fig 3. Changes in landscapes if channel scale charateristic

Fig 4. Changes in mean values of the shoreline index. Error bars indicated ±SD. The maen values with different symbols differ sigficantlly (P<0.001, t-test)



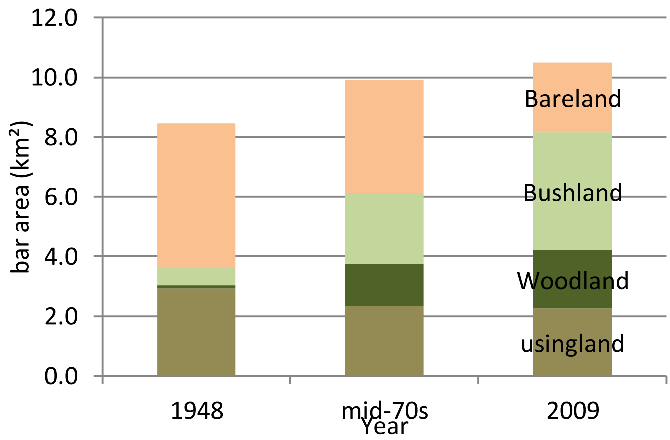


Fig 5. Changes in values of the sunousity. Error bars indicated ±SD. The maen values with different symbols differ sigficantlly (P<0.001, t-test)

Fig 6. Changes in landscapes of scale characteristic

4.2. Aquatic habitat characteristics

4.2.1 lotic habitats

The mean of riffle area was the highest in 1948 ($p<0.0005$, t-test). It decreased continuously from 1948 into it's one-fourth in 2009. However, the number of riffles showed an increase in mid-70s and then decreased dramatically into a half number in 2009 (Table 2).

4.2.2 lentic habitats

Lentic habitat was comprised of active pool, terrace pool, bar head backwater, bar tail backwater. (Table 2) The mean of active pool area decreased ($P=0.01$, t-test) and the number also decreased from 1948 to mid-70s significantly. And then, area increased from mid-70s to 2009 ($P=0.08$, t-test).

The mean of terrace pool area showed a increases from 1948 to 2009 ($p=0.03$, t-test). The mean of bar-head backwater area increased ($p=0.1$, t-test) from 1948 to 2009 gradually. The mean of bar-tail backwater area also increased ($p=0.7$, t-test) with similar difference.

Table 2. Historical changes in the mean area of each aquatic habitat within a unit reach(1 km) in the Kizu River

Year	Lotic		Lentic							
	Riffle		Pool				Backwater			
			Active		Terrace		bar-head		bar-tail	
	Mean area ±SD(m²)	n	Mean area ±SD(m²)	n	Mean area ±SD(m²)	n	Mean area ±SD(m²)	n	Mean area ±SD(m²)	n
1948	33,209 ± 21,503	105	2,423 ± 3,822	72	372 ± 737	38	107 ± 387	2	853 ± 1,611	9
mid-70s	13,992 ± 7,847	124	480 ± 756	46	657 ± 1246	40	301 ± 564	7	1,053 ± 2,508	13
2009	7,691 ± 4,885	64	906 ± 1,097	86	1,429 ± 1,964	120	482 ± 757	17	1,213 ± 1,897	39

SD= standard deviation

Habitat richness was 2.5, 2.7and 3.8 on average in 1948, mid-1970s and 2009, respectively and the one-way ANOVA analysis resulted in significant difference among the years ($P<0.0001$, one-way

ANOVA)(Fig. 7). Although habitat richness in 2009 was significantly higher than 1948 and mid-1970s, those in 1948 and mid-70s were not (*ns*, t-test).

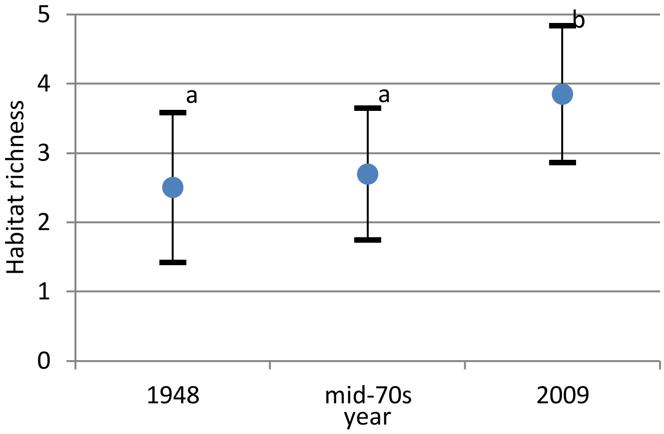
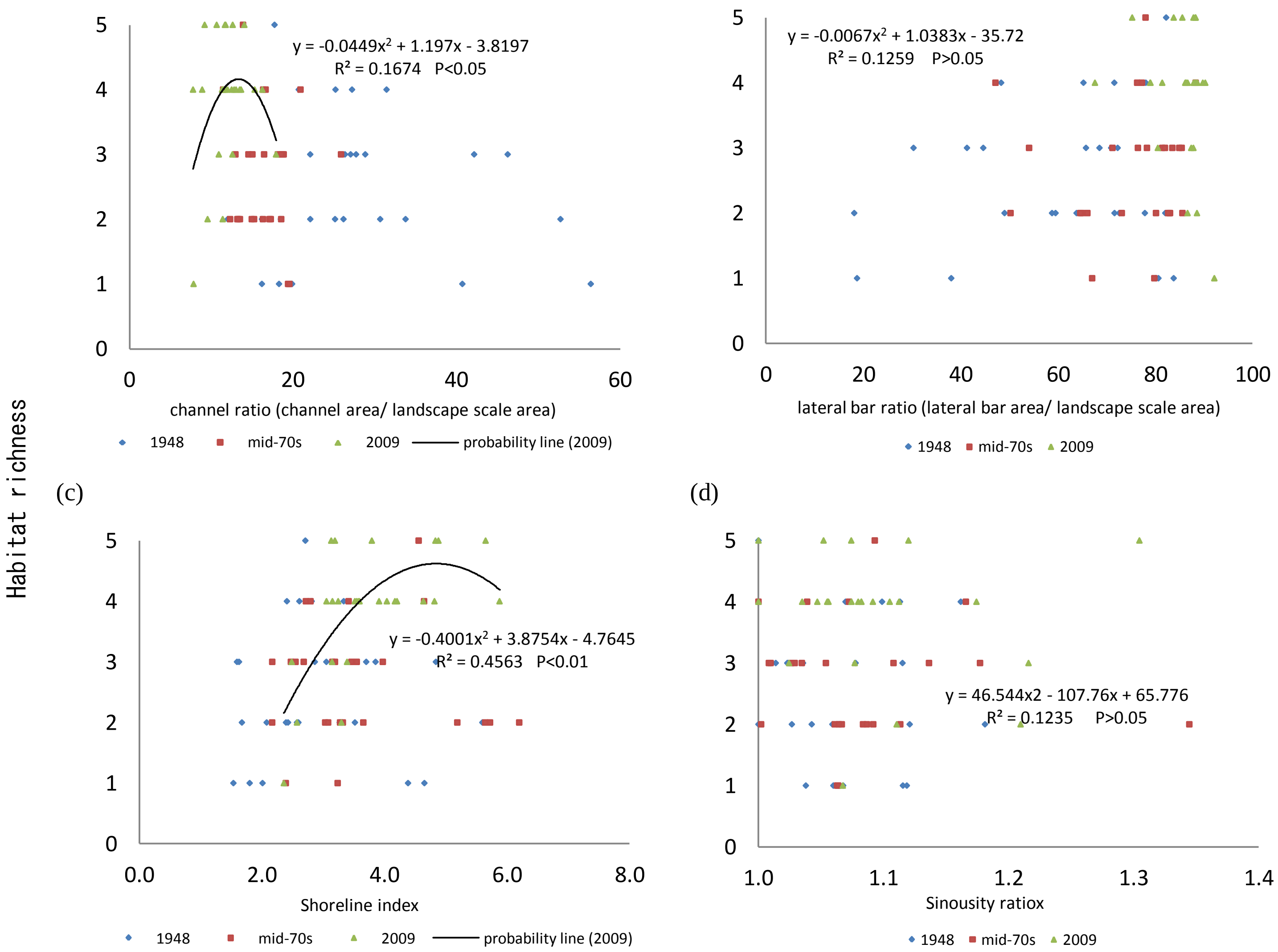


Fig 7. Historical changes in habitat richness in the Kizu River. Error bars indicated ±SD.

(a) (b)



(c) (d)

(e) (f)

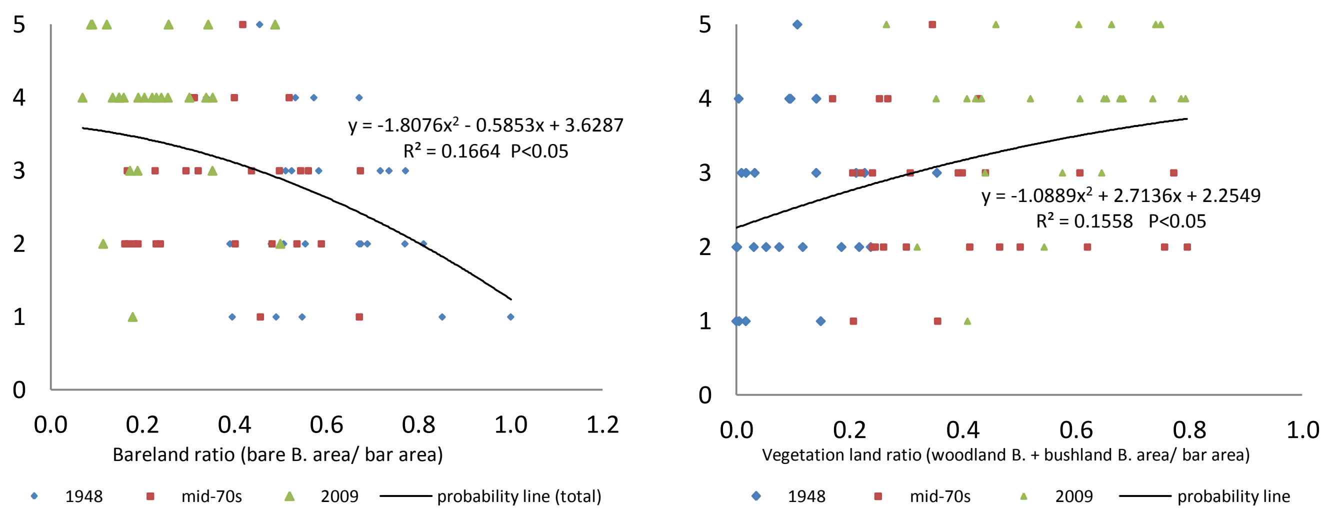


Fig 8. Relations habitat richness to each landscape characteristic. Measured variables: channel scale characteristic (a~d), bar scale characteristic (e,f)

4.3. Relations of aquatic habitats to landscape characteristics

4.3.1 Habitat richness & channel scale characteristics

Relationship between habitat richness and channel ratio, lateral bar ratio did not have relation definitely (Fig. 8a; 8b). However, analysis of habitat richness to channel ratio related in slightly in 2009. In 2009, maximum of habitat diversity had from 13 to 14 into channel ratio. Because lateral bar ratio distributed high value all years, it was difficult to analyze correlation between lateral bar ration and habitat richness.

Regression analysis of habitat richness to shoreline index related significant in 2009 (Fig. 8c). In 2009, Habitat richness shows the maximum value between 4.5 and 5.0 of shoreline index. In contrast to shoreline index, the habitat richness did not show correlation with sinouisty (Fig. 8d).

4.3.2 Habitat richness & bar scale characteristics

Relationship between habitat richness and bar scale characteristics also did not show relation significantly (Fig. 8e; 8f). However, habitat richness showed week probability with bareland ratio negatively, whereas that correlated with vegetation-land bar ratio positively.

5. DISCUSSION

The classification categorizes aquatic habitat structures into detailed types depending on spatial scale of habitat used by fishes, birds and macro-invertebrates such as aquatic insects and crustaceans. The classification considers the spatial distribution of riffles, pools, and backwater for a habitat spatial scale and shoreline for a microhabitat special scale. Although the classification of habitat have to consider not only landscape characteristics but hydraulic conditions such as water velocity, slope, and sediment size, etc., we intend to make the habitat classification based on only aerial photographs at first and then interpret the relationship among these factors, because the simple method of the present study enable habitat assessment for past years in terms of Landscape ecology.

The dam construction has great impacts on landscape and hydrology, so it is of scientific importance to investigate and evaluate the landscape changes induced by dam construction. (Qinghe, 2011). Because discharge and sediment was controlled due to artificial impact such as construction of dam and levee, excavation, area of lateral bar and vegetation land ratio increased by small frequency of disturbance. In this perspective, according to decreasing the area of water surface and increasing the area of lateral bar, it was natural result that area of riffle decreased. It was necessary to examine relation between changes of landscape and habitat diversity constantly for improvement of biodiversity and restoration of endemic species. Habitat richness in The Kizu River increased significantly (Fig. 7) with increasing the area and number of terrace pool, backwater from 1948 to 2009. Number and area of active pool decreased from 1948 to mid-70s and then increased from mid70s to 2009. In contrast, area of riffle decreased and number of riffle increased from 1948 to mid-70s. We suggest correlation between active pool and riffle with inverse proportion slightly (Fig. 9). To change between water surface and bareland occurred continuous due to changing of flow and sediment transport. In many cases, active pool increased with sediment deposits instead of water surface and riffle increased with division of lateral bar.

Most studies emphasise the scale-depedant nature (spatially and temporally) of equilibrium concepts (DeAngelis and Waterhouse, 1987; Wiens, 1989; Turner et al., 1993). Wien(1984) argues that an equilibrium state generally cannot be reached due to the high frequency of natural disturbances (Hohensinner et al., 2011). This study considered the relations of habitat richness to landscape scale characteristics. Among various variable, channel ratio and shoreline index, bareland ratio and vegetation land ratio were related to habitat richness. The result proved hypothesis reviewed slightly. In case of channel ratio and shoreline index, had maximum value for the highest habitat richness. In the Kizu River, as increasing the vegetation ratio, habitat diversity increased compare with period was comprised most of bareland and water surface. In the reason, we suggest that habitat diversity will decrease in the case that bareland ratio reaches to 0 or vegetation ratio reaches to 1.

According recent report of Kizu River (Kizu River research Group, 2009), biodiversity increased gradually, whereas endemic species have disappeared and exotic species have increased in Kizu River. Because biodiversity was influenced not only habitat characteristics but environmental factor and hydraulic conditions such as water temperature, water quality, sediment size, etc., biodiversity should consider habitat diversity and each hydrogeomorphic habitat characteristics.

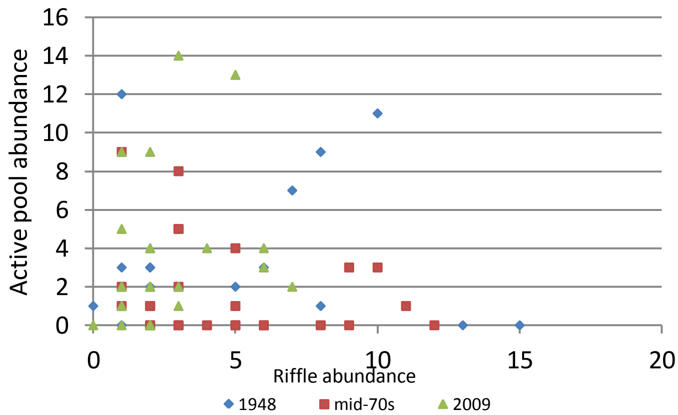


Fig 9. Relations between active pool abundance and riffle abundance in the Kizu River.

6. CONCLUSION

The Kizu River had increased habitat richness with increasing area of vegetation-land (Fig. 8f). Results of the landscape changes showed that bar area and shoreline index in the channel scale increased with decreasing water surface, and at the same time, bareland decreased with increasing bushland and woodland. The significant increase of habitat richness during the period indicated that the increase of vegetation area contributed to raising habitat richness to some extent. Therefore, the stability of flow regimes and reduction in sediment dynamics fascinated the environmental heterogenety in there 60 years in the Kizu River.

To examine a hypothesis of the optimal landscape characteristics to maximize habitat richness, it is required to increase data plots.

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