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Relations of Lentic Habitat Conditions and Abundance of Bitterling and Mussels to Reach Scale Channel Configuration in the Kizu River

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Synopsis

The Kizu River, a branch of the Yodo River in the middle Japan, had experienced riverbed degradation and vegetation expansion in response to peak-cut in discharge and reduction in sediment dynamism after sand excavation and dam construction in these 60 years. This paper described relations among abundance of fish and mussel communities, habitat structures and reach-scale channel configuration (RSCC) to link between micro habitat scales and reach scales with temporal approach. As for relations between present species and past habitat conditions, bitterling was best explained by a model one year ago, and mussel was best explained by a model consist of flooding frequency and depth of mud two years ago. According to relations between species and habitat conditions in same year, terrace ponds having flood frequency between 8 and 22 days/ year were the most values for bitterlings and mussels. Concave floodplain with shape index between -0.25 and -0.05 tended to have high number of habitats having frequency between 8 and 22 days/year, and Kizu River in 2000s seemed to have higher potential habitat suitability of bitterling and mussel than before.

Keywords: bitterling and mussel, flooding frequency, floodplain vertical shape index

1. Introduction

In the last decade, many rivers had experienced riverbed degradation and vegetation expansion in response to peak discharge and flood frequency (Williams and Wolman, 1984). These river channel alternations have led to deterioration of habitat conditions. Especially, the Kizu River was known as many lentic ponds or wando providing habitat to bitterlings and unionid mussels. However, the diversity of bitterling and mussels decreased, and representative protected bitterling '*Acheilognathus longipinnis*' had disappeared by reduction of connectivity with main channels after sand excavation and dam construction (Kizu River Research Group, 2003). To improve river health, it is needed to find out habitat conditions are required for diversity of bitterlings and mussels. Mussels could be used as an indicator of fish communities because of various symbiotic relationships (Negishi et al., 2013; Haag and Warren, 1998). Reproduction of mussels requires gobby fish as host (Haag and Warren, 1998) and bitterlings used mussels for spawning redd (Yoshihiro and Takashi, 2010). Thus, bitterling and mussel are useful to evaluation habitat conditions for animal communities not only mussels but also fishes.

In other to understand the intrinsic relations of bitterlings and mussels to habitat conditions, it is important to analyze effects of nor only present habitat conditions but also past conditions. The survival of mussels depends on the interaction of several biotic and abiotic factors operating at different spatial and temporal scales (Morales et al., 2006; Haag and Warren, 1998). Because successful reproduction requires the availability of an appropriate host fish at the appropriate time and that juveniles find favorable habitat, mussels had possibility that they were related with spatial diversity as well as time lag.

Habitat conditions for bitterling and mussel within local scale should be linked with geomorphological conditions in larger scales. Frothingham et al. (2002) said linkages between geomorphological conditions and aquatic ecosystems via the influence of fluvial processes could be helped by the management of complex fluvial systems. Although changes in reach and large-scale watershed characteristics can affect community composition and environmental condition (Poole and Downing, 2004), much of the study of mussel-habitat relationships has been performed on the scale of the local scale (Tiegs et al., 2009). These relations are difficult to understand processes and mechanisms of creation and maintenance of habitats and habitat conditions responded to changes of disturbance. Thus, multiple spatial scales are a critical consideration for understanding ecological patterns (Tiegs et al., 2009).

Purposes of this study area 1) to clarify the amount of time lag between habitat changes having a significant influence on species abundance of bitterling and mussel, 2) to understand habitat parameters having a dominant role on species abundance, 3) to link habitats and reach-scale channel configuration (RSCC) and 4) to show appropriate RSCC supporting habitats for bitterling and mussels and to estimate historical changes in potential habitat suitability.

2. Method

2.1 Study area

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). The Kizu River has been called a typical sandy river derived from weathered granite in the upper stream. A total of 5 dams, Takayama Dam (constructed in 1969), Syourenji Dam (1970), Murou Dam (1974), Nunome Dam (1992), and Hinachi Dam (1999), are located in the basin. The peak discharge is caused by seasonal typhoons in summer and autumn. The largest flood event occurred in 1959 and reached almost 6000 m^3/s, whereas intensity of peak

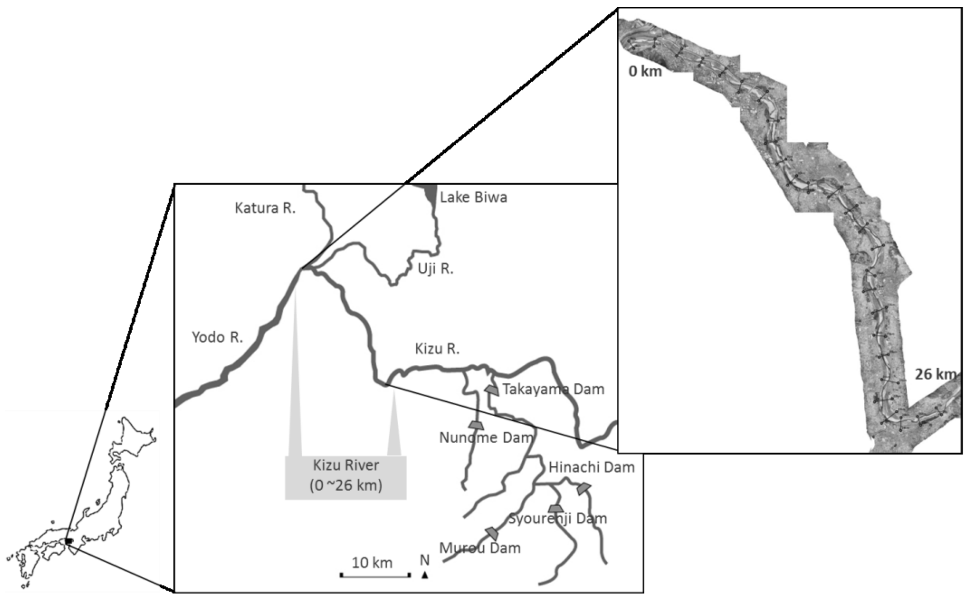

Fig. 1 A map of the Kizu River

discharge decreased by about 3,000 m^3/s after dam construction. The annual mean bed-load transported to the lower reach was estimated to be about 183,000 m^3/y in the 1960's, but about 23,000 m^3/y in the 2000's (Ashida et al., 2008). Due to sediment reduction resulting from sand excavation between 1958 and 1963 and dam construction, riverbed degradation was accelerated and continued until now, especially in the lower reach (0 -10 km) (Ashida et al., 2008).

2.2 Abundance of bitterlings and mussels

We used data of abundance of bitterlings and mussels were surveyed by ASIA AIR SURVEY CO., LTD. Total number of 120 floodplain ponds was surveyed in 2007, 2009, 2010 and 2011. Abundance indicated number of individual of bitterling and mussel, and they divided by surveyed time and number of attended people for impartial comparison. In temporal relations between present species and past habitat conditions, just 27 ponds having surveyed data of habitat conditions from 2007 to 2011 were used. In contemporary relations between species and habitat conditions in same year, all 120 ponds were used. After finishing relations between specie and habitat conditions, suitability index (SI) of bitterling and mussel was calculated to find out relation with suitable habitat conditions. Based on averaged abundance per range of explanatory values, maximum values were transformed to 1 and minimum values were to 0.

2.3 Lentic habitat structures

A total of 9 parameters of habitat condition were selected: area, water depth, mud depth, mean grain size, DO, chlorophyll, wood coverage (shaded shoreline ratio by wood), relative height and flood frequency (Table 4). In the temporal relations, location, age and transparency were added as habitat conditions. Relative height was calculated by the lowest height between water level of main channel and level of 5 m buffer around ponds using DEM data. Flooding frequency was calculated by simulation using DEM data and water discharge of 10 years (0: no, 1: 1 time, 2: 8 times, 3: 16 times, 4: 22 times, 5: 45 times, 6: 71 times, 7: 185 times and 8: 365 times flooding per 1 year). Lentic habitat types were classified into bar head-active pond (BH-AP), bar head-terrace pond (BH-TP), bar tail-active pond (BT-AP) and bar tail-terrace pond (BT-TP) in the just relations between species and habitat conditions in same year.

Table 1 Historical changes of averaged habitat conditions were surveyed 27 ponds (mean ± standard error)

	Transparency (%)	Mud depth (m)	Mean grain size (mm)	DO (mg/l)	chlorophyll (μg/l)	Wood coverage (%)	Relative height (m)	Flood frequency
2007	36.5±26	6.21±8.5	21.3±16	9.9±4.0	40.1±11.5	3.1±8.5	1.1±1.2	3.8±2.3
2009	30.0±16	5.6±7.0	22.8±19	10.1±5.3	110.0±118	5.5±22.3	0.76±0.3	3.4±1.4
2011	36.2±17	12.5±7.4	11.4±8.8	6.8±4.1	41.5±50.1	23.2±30.1	1.3±0.5	2.6±1.4
2012	27.2±15	5.9±5.1	12.7±16.7	6.5±1.7	22.6±21.0	30.0±32	1.3±0.5	2.4±1.5

Table 2 Results of generalized linear model tested the relations of abundance of species in 2011 and habitat conditions in 2007, 2009, 2010 and 2011)

Abundance	Model		n	Year	Wald χ^2	p-value
	Statistic data	Field survey data				
Bitterling	Location + age	Transparency + mean grain size + DO	5	2011	1.81	.177
				2010	3.83	.050
				2009	1.84	.174
				2007	3.15	.076
Mussel	Flooding frequency	Depth of mud	2	2011	0.56	.454
				2010	1.99	.157
				2009	12.18	.000
				2007	5.90	.015

2.4 Parameter of reach-scale channel configuration (RSCC)

Reach-scale was divided into 2 km units according to the mean wavelength of meandering channels in the Kizu River. Floodplain vertical shape index (FVSI) was used as representative parameters of RSCC, because changes of FVSI significantly related with changes of channel plan-form, e.g. channel width, number of channels, ratio of vegetation, and of cross-section (Choi et al., 2013). FVSI was calculated by difference of integral values of relative elevation of riverbed to normal water level and those of uniformly distributed elevation within a 2 km unit based on cross-sectional profiles at intervals of 200 m (Takemon etl al., 2013).

FVSI shows a degree of convex or concave shape in the altitude distribution of the floodplain. The positive value is reflected in the convex vertical shape, and the negative value is reflected in the concave vertical shape. Values of FSVI were calculated based on data of 7 years in 1961, 1971, 1979, 1990, 2002, 2006 and 2010. Only results of two years (2006 and 2010) were connected with habitat structures, and other yearly data were used to estimate potential habitat suitability.

2.5 Statistical analysis

To understand relations between species abundance and the past habitat conditions, we used generalized linear model (GLM) with a Poisson error assumption and a long link function. The best model was selected based on Akaike's Information Criterion (AIC; Akaike, 1974), and Chi-squared (χ^2) was used to compare effect of past and recent conditions on abundance of bitterling and mussel.

Table 3 Results of correlation analysis tested relations between abundance of species and habitat conditions were used in model. Relations between bitterling richness in 2011 and habitat conditions in 2010. Relations between mussel richness in 2011 and habitat conditions in 2009, and relations between fish richness in 2011 and habitat conditions in 2011 (r values. *** p<0.001, * *p<0.01, * p<0.05)

	Low R.H.	age	location	Flooding frequency	area	Veg. coverage	DO	transparency	Mean grain size	Depth of mud
Abundance of bitterlings		.220	.331				-.203	-.151	-.007	
Abundance of mussels				-.454***						-.524***

In relations between species abundance and habitat conditions in same year, multiple and single regression analysis were used. The best model was selected based on Akaike's Information Criterion. An α value of 0.05 was used to indicate statistical significance for all tests. All analyses were conducted using SPSS version 19 (SPSS 19.0, SPSS Inc).

Table 4 Averaged habitat conditions across all surveyed 120 ponds and each pond type (mean ± standard error). n= BH-AP (31), BH-TP (28), BT-AP (21), BT-TP (40)

	Area (m2)	Water depth (m)	Mud depth (m)	Mean grain size (mm)	DO (mg/l)	chlorophyll (μg/l)	Wood coverage (%)	Relative height (m)	Flood frequency
All ponds	507±882	46.7±23.6	8.1±10.0	3.6±4.8	9.8±4.7	90.1±145.1	11.1±19.7	1.4±1.2	3.5±2.1
BH-AP	390±611	48.7±22.4	5.4±6.5	3.7±4.1	10.2±3.5	40.6±63.1	4.3±10.9	0.9±0.5	4.5±1.8
BH-TP	411±494	42.7±25.5	7.9±8.9	4.3±5.5	10.3±4.8	54.4±81.9	10.6±21.4	2.0±1.5	2.7±1.6
BT-AP	678±879	51.9±28.8	5.4±8.8	3.4±3.2	9.2±4.9	28.5±35.8	8.7±14.7	0.7±0.3	5.4±1.9
BT-TP	575±1218	45.2±20.2	11.6±12.5	3.0±5.5	9.6±5.4	185.7±203.9	18.1±24.2	1.8±1.3	2.2±1.6

Table 5 Abundance of bitterlings and mussels across all 120 ponds and each pond type (mean ± standard error). n= BH-AP (31), BH-TP (28), BT-AP (21), BT-TP (40)

	Abundance of bitterlings	Abundance of mussels
All ponds	7.0± 20.2	15.7± 43.2
BH-AP	3.1± 6.7	4.2± 17.8
BH-TP	3.6±5.6	27.6± 57.4
BT-AP	2.6± 5.0	4.9± 12.6
BT-TP	14.7±32.9	21.9± 52.6

Table 6 Results of multiple regression analysis that examined the best models of habitat conditions for abundance of bitterlings and mussels

	Area (m2)	Water depth (m)	Mud depth (m)	Mean grain size (mm)	DO (mg/l)	chlorophyll (μg/l)	Wood coverage (%)	Relative height (m)	Flood frequency
Abundance of bitterlings			-0.6 (0.24)			0.08 (0.26)		-7.8 (0.26)	-3.0 (0.24)
Abundance of mussels	0.01 (0.16)						0.41 (0.16)	-15.8 (0.18)	-8.7 (0.18)

Habitat parameters were included as independent variables in the best models on the basis of Akaike's Information Criterion. (Regression coefficients presented for each best model, parenthesis indicated level of contribution).

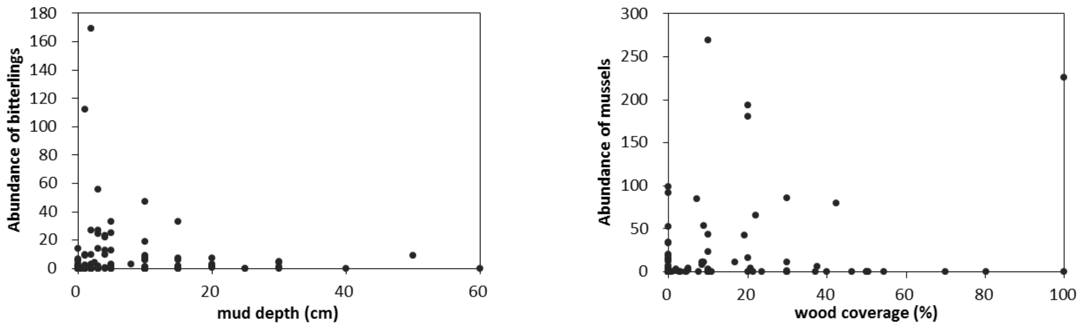

Fig. 2 Relations of (a) mud depth to abundance of bitterlings and (b) wood coverage to abundance of mussels

3. Results

3.1 Relations of abundance of bitterlings and mussels to the past habitat conditions

Table 1 showed the historical changes of habitat conditions were analyzed of 27 ponds. Table 2 showed results of generalized linear model tested the relations of species abundance to present and past habitat conditions of 27 ponds. Bitterlings were best explained by a model consist of location, age, transparency, mean grain size and DO one year ago ($\chi^2 = 3.83$, $P = 0.05$). Mussels were best explained by a model consist of flooding frequency and depth of mud two years ago ($\chi^2 = 12.18$, $P < 0.001$).

However, bitterlings had no significant correlations separately (Table 3). Mussels were negatively correlated with depth of mud ($R = -0.524$, $P < 0.05$) and flooding frequency ($R = -0.454$, $p < 0.05$).

3.2 Relations of bitterlings and mussels to habitat conditions

Bitterlings were observed at 63 ponds and mussels were observed at 47 ponds among 120 ponds. Values of habitat conditions per pond types were shown in Table 4 and abundance of bitterlings and mussels were shown in Table 4. Terrace ponds (BH-TP, BT-TP) had deeper mud depth, more chlorophyll and wood coverage, higher relative height and lower flood frequency than active ponds (BH-AP, BT-AP). Especially, pond type of BT-TP had the maximum values in mud depth, chlorophyll and wood coverage (Table 4). Pond type of BT-TP had the maximum abundance of bitterlings among all pond types. Abundance of mussels showed more values in terrace ponds (BH-TP and BT-TP) than active ponds (BH-AP, BT-TP).

Best model for abundance of bitterlings and mussels were selected based on habitat conditions of all pond types (Table 5). Mud depth tended to have negative relations with abundance of

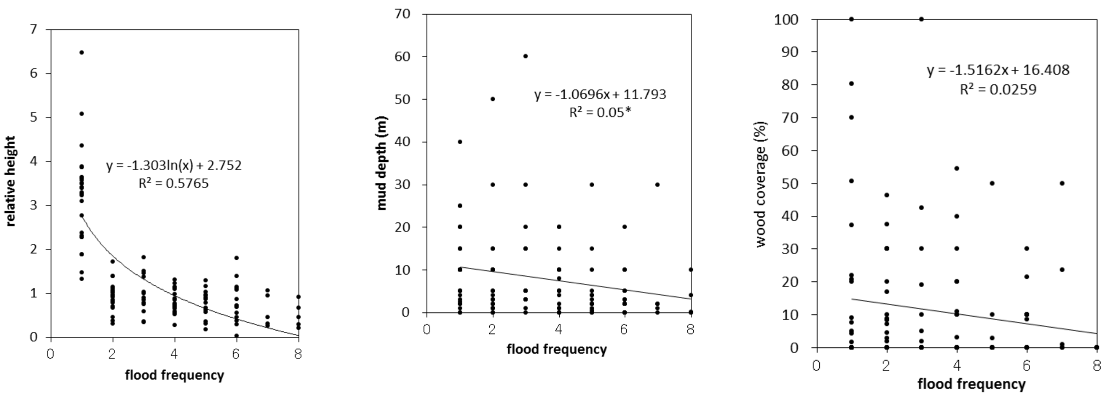

Fig. 3 Relations of flood frequency to (a) relative height, (b) mud depth and (c) wood coverage

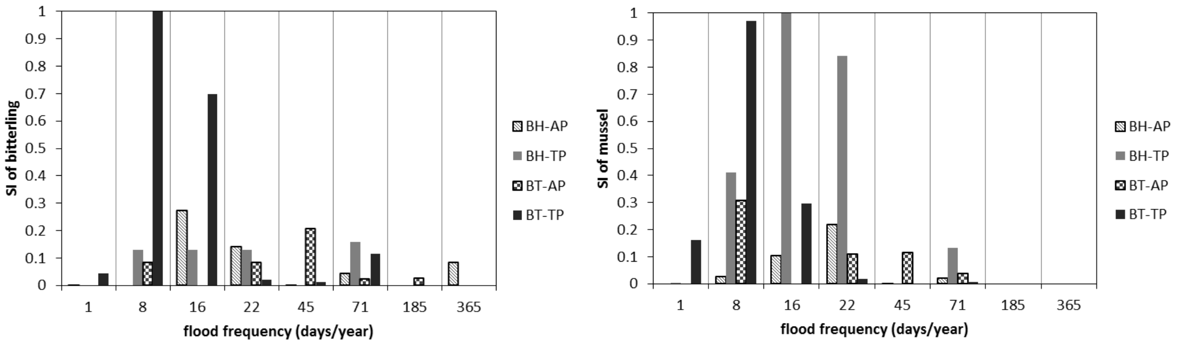

Fig. 4 Relations of flood frequency to (a) SI of bitterling and (b) SI of mussel

bitterlings (Table 5, Fig. 2a) and chlorophyll had positive relations. Habitat size and wood coverage were positively related to abundance of mussels (Fig. 2b). Relative height and flood frequency were important variable in explaining abundance of bitterlings and mussels, because they were selected in both models. These two parameters had significant correlations each other (Fig. 3a) and had correlations with abundance of bitterling and mussels. Flood frequency also tended to have relations with mud depth and wood coverage even though they had low coefficients (Fig 3b, 3c). Although flood frequency did not have relations with habitat size, we determined flood frequency as key parameters reflecting habitat conditions for abundance of bitterlings and mussels, because past flood frequency also had relations with present abundance of mussels.

Parameter of flood frequency was related with suitability index (SI) of bitterlings and mussels (Fig 4). SI of bitterling tended to have high values between 8 and 16 days/year of flood frequency (Fig. 4a). Flood frequency between 8 and 22 days/year had the maximum values of abundance of mussel (Fig. 4b).

3.3 Relations of habitat conditions and types to RSCC

Floodplain vertical shape index as parameter of RSCC was categorized into 6 groups (Fig. 5). Number of ponds having different flood frequency was counted by categorized values of FVSI (Fig. 5a). All ponds detected on aerial photos (n=386) as well as surveyed ponds were used in this relation. Number of ponds having flood frequency between 8-22 days/year showed the maximum values in FVSI between -0.25 and -0.15, and between -0.15 and -0.05. Reach with FVSI less than -0.35 had high number of ponds with frequent flood such as 45 or 71 days/year. On the other hand, number of

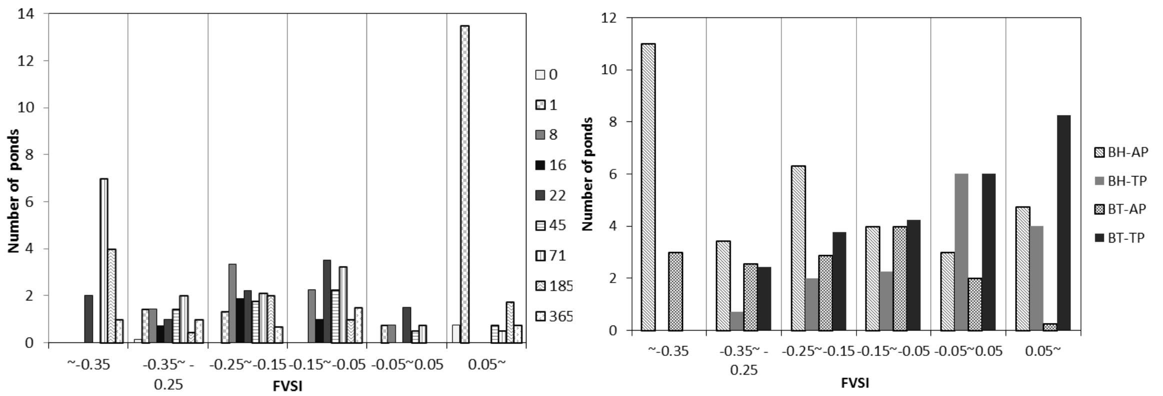

Fig. 5 Relations of floodplain vertical shape index (FVSI) to (a) number of ponds with different flood frequency and (b) number of pond types.

ponds having 1 times/year of flood frequency significantly increased in FVSI exceeding 0.05. Number of pond types was also counted by values of FVSI (Fig. 5b). Pond types of BH-TP and BT-TP increased on reach with FVSI exceeding -0.05 and number of ponds of BT-TP showed the maximum values in FVSI exceeding 0.05. In contrast, number of active ponds (BH-AP, BT-AP) had the maximum values in FVSI less than -0.35. Pond types tended to change from active ponds to terrace pond with increase of values of FVSI. Although number of terrace ponds increased in FVSI exceeding 0.05, they could not say suitable habitats for bitterlings and mussels, because these terrace ponds tended to have less flood frequency (0 or 1 days/year). Thus, reach having FSVI between -0.25 and -0.15 tended to have a lot number of ponds with suitable flood frequency for bitterling and mussels.

3.4 Historical changes of FVSI and habitat suitability of bitterling and mussels

Historical values of FVSI were plotted in Fig. 6. Mean FVSI significantly increased from -0.44 in 1961 to -0.17 in 2010. Suitable reach having FVSI between -0.25 and -0.15 tended to have more in 2000s, and reaches with FVSI exceeding 0.05 were detected only in 2000s. On the other hand, many reach with FVSI less than -0.35 were seen in before 2000s. Thus, RSCC of the Kizu River before 2000's seemed to have higher potential SI of bitterling and mussel.

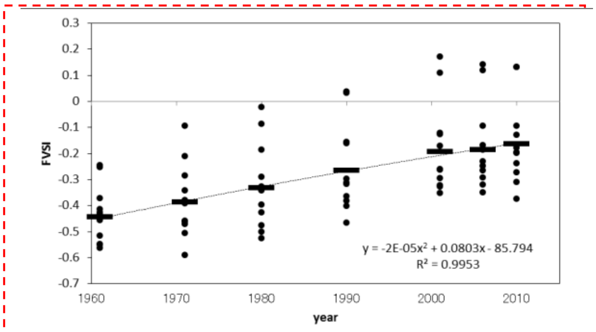

Fig. 6 Historical changes of FVSI

4. Discussion

Many previous studies examine relations with mussel or bitterling and various habitat factors such as current velocity, sediment size, water depth (Johnson and Brown, 2007) or shear stress (Negishi et al., 2002). However, most of studies focused on lotic habitats or semi-lentic habitat such as backwaters. In case of lotic habitats depended on connectivity with main channels, we should consider other parameters, and we supposed flood frequency is one of important attributes in explaining bitterling and mussel distribution. Parameters of flood frequency may influence various environmental factors directly or indirectly. Ponds having flood frequency between 8 and 16 days/year were suitable habitats for both abundance of bitterlings and mussels, besides ponds with 22 days/year of flood frequency also were suitable for SI of mussel. Negishi et al. (2002) said flood frequency was important for mussels, and they compared with other potentially important environmental variables (ORP, organic matter and chlorophyll) within local scale. They explained low inundation frequency tended to results in high levels of chlorophyll. Our results also terrace pond having low flood frequency tended to have high chlorophyll (Table 4), and it was positively related with abundance of bitterlings (Table 5). Abundance and SI of bitterling and mussel tended to increase in more stable ponds than unstable ponds such as active ponds under conditions with appropriate flood frequency. Abundance of mussels showed more values in terrace ponds (BH-TP and BT-TP) than active ponds (BH-AP, BT-TP), and ponds type of BT-TP had the maximum abundance among all pond types. Abundance of bitterling and mussel seem to be influenced by locations as well as environmental and geomorphological habitat conditions. Since outside of bend occurred erosion with fast flowing water and lots of energy, especially flooding time, bar head terrace pond is nearly located at outside of bend may be more unstable than bar tail terrace pond on inside of bend within meandering channel. Specially, fish such as bitterling may be highly influenced by flowing than mussels.

In addition, we should consider not only present habitat conditions but also the past conditions for bitterlings and mussels. Our results showed species richness of mussel was influenced by habitat conditions 2years ago. It may assume that mussels were reproduced or flowed from main channel in the past. Because freshwater mussel was taken about 5 years from reproduction to adulthood (Mahon and Bogan, 2001), a time lag maybe exist between current species richness and past habitat conditions.

Our study indicated the abundance of species or habitat conditions were influenced by changes of geomorphic channel configuration was characterized by FVSI. Reach with concave floodplain shape tended to flood frequently, and then, number of ponds having high flood frequency increased with increment of active ponds. On the other hand, reach with convex floodplain shape tended to be difficult to flood, therefore number of ponds having low flood frequency increased with terrace ponds. Frequently flooded ponds tended to exist on reach with significant concave floodplain shape, whereas ponds having low flood frequency tended to exist convex floodplain shape. Choi M. et al.(2013) examined the Kizu River experienced channel narrowing and decreasing number of channels with significant increase in FVSI by reduction of peak discharge and sediment supply recent 50 years. According these changes, habitat diversity sometimes decreased by significant increase of terrace ponds. Therefore, riverbed management focused on sediment supply is proposed to prevent riverbed degradation and to improve river ecosystems. If many case studies carry out using multiple scale analysis like this study, we could suppose proper volume of sediment or discharge according to connection with historical changes of reach scale channel configuration.

5. Conclusion

Multiple spatial and temporal scales should be considered in river restoration project because ecological processes are always laid across the different scales. We suggest method to link between microhabitat scales and reach scales for abundance of bitterlings and mussels in the Kizu River. Our results showed suitable habitat conditions should be maintained for bitterlings and mussel, because they had relations with habitat conditions one year ago or two years ago. As for relations between species abundance and habitat conditions with structures, terrace ponds had higher abundance of bitterlings and mussels than active ponds. In addition, terrace ponds having flood frequency between 8 and 22 days/ year were the most suitable habitats. Number of the suitable habitats increased on concave floodplain with FVSI values between -0.25 and -0.05, whereas unsuitable habitats having 1 days/year of flood frequency increased on convex floodplain with FVSI exceeding 0.05. The Kizu River in 2000s having high number of suitable habitats seemed to have higher potential habitat suitability of bitterling and mussel.

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