Evaluation of Cross-sectional Geomorphology for Lentic Habitat Restoration in the Uji River

Jue WANG[(1)], Yasuhiro TAKEMON and Tetsuya SUMI

(1) Graduate School of Engineering, Department of Urban Management, Kyoto University

Synopsis

Most of rivers in civilized countries have lost biodiversity due to deterioration of habitats by the artificial river works such as channelization, sand mining and dam construction. The Uji River is a typical river suffered by degradation and bipolazation of the riverbed due to reduced sediment dynamism and step-wise flow regime caused by the gate operation at Seta Barrage for control the discharge from the Lake Biwa, leading to decreased the connectivity of the main channel and the bank side lentic habitats. In this paper, we analyzed relations of aquatic animal communities in lentic habitats to the riverbed geomorphological parameters such as relative height of the habitat to the main channel, the length of cross-sectional perimeter, floodplain vertical shape index (FVSI), and clay layer distribution. Based on the results, the lentic habitats were classified into three types: 1) Low relative height ponds with high biodiversity with taxonomic groups common with lotic habitats, 2) terrace ponds with intermediate and high relative height with low biodiversity with taxonomic groups common with moor-like still water habitats, 3) island bar ponds with high relative height with rather high biodiversity. In addition, we found that the location of these lentic habitats showed a fairly good correspondence to the clay layer distribution. Based on these interrelationships, we proposed a method for evaluation of lentic habitat potential combining a suitable relative height with the underground clay layer distribution. This method will be applicable to nature restoration plans for creation of lentic habitats in degraded rivers in general as well as in the Uji River.

Keywords: Uji River, riverbed degradation, lentic habitat, nature restoration, clay layer

1. INTRODUCTION

1.1 Background

Most of rivers in the civilized countries have lost biodiversity due to deterioration of habitats through the riverbed degradation derived from various artificial works such as channelization, sand mining and dam construction (Wohl, 2014). For the nature conservation in these human impacted rivers, restoration of habitats is required on a priority basis (Takemon, 1997; 2010).

This study focus on the Uji River originates from the Lake Biwa, the largest Lake in Japan (Fig. 1). This river has been reduced in sediment dynamism due to the impact of the Amagase Dam constructed in 1964 and sand mining in 1960s resulted in degradation and bipolarization of river channel, which decreased the connectivity of the main channel and lentic habitats on the banksides, affecting the ecological environment of biological communities. The lateral connectivity among main channels and pools on the floodplain has been a notable issue for nature restoration (Ormerod et al., 2011) as well as the longitudinal connectivity in river ecosystems

(Guillon et al., 2019).

After redevelopment of the Amagase Dam in 2022, the planned peak discharge will be increased up to 1,500 m^3/s in the near future (Lake Biwa River Bureau, 2022). Accordingly, the Yodo River Bureau intends to enlarge cross-sectional area of the Uji River by excavating the riverbed for increasing the ability of the peak discharge (Yodogawa River Bureau, 2021). Because the cross-sectional riverbed geomorphology is crucially important for lateral connectivity in riparian ecosystems (Nagayama et al., 2015), it would be a good chance to restore the deteriorated nature in this river, if we could propose a target design for creating suitable habitat structure on the bankside.

1.2 Objectives

Under the above background, this study aims to develop a new method for evaluation and creation of lentic habitats on the bank-sides in the degraded rivers, based on interrelationships among the composition of animal communities in the lentic habitats, and river channel geomorphology, such as relative height of the habitat elevation to the annual normal water level, the length of cross-sectional perimeter, floodplain vertical shape index (FVSI) after Takemon et al. (2013), and underground clay layer distribution.

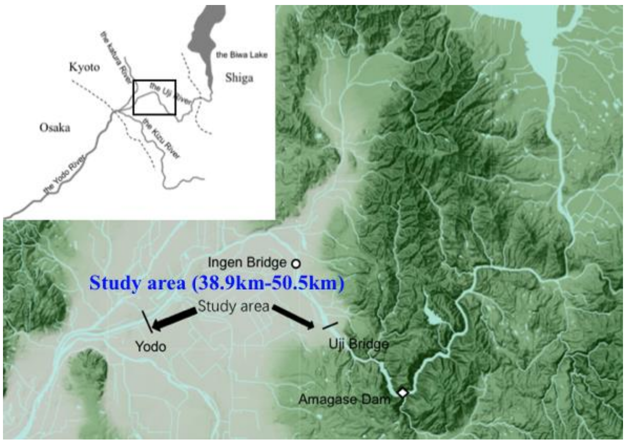

Fig. 1 Map of the Uji River and the study area (38.9-50.0kp). Here, "kp" means a distance from the Yodo River mouth.

2. STUDY AREA

2.1 Location of study area

The study was conducted in the lower reaches of the Uji River, a tributary of the Yodo River, between Yodo (38.9kp) and Uji Bridge (50.0kp) （Fig. 1）. Analyses of relative height of the habitat to the main channel, the length of cross-sectional perimeter, floodplain vertical shape index (FVSI) (Takemon et al., 2013), and underground clay layer distribution were conducted in the whole study area.

2.2 Field Survey sites

The field survey was carried out in three reaches a: right bank side at 46.8-47.0kp below Ingen Bridge, b: left bank side and bar island at 46.2-46.6kp, and c: bar island at 48.6-49.0kp below Keiji Bypass in the Uji River (Fig 2). A set of field surveys on environmental conditions and biological communities were conducted in aquatic habitats within these reaches in 2021.

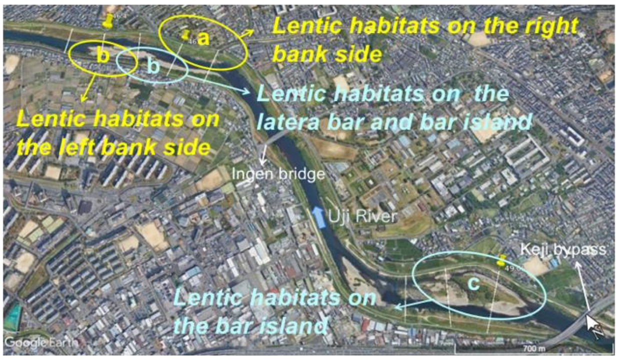

Fig. 2 Map of field survey area (46.2-49.0kp). a: right-bank side terrace, b: left-bank sidebar below the Ingen Bridge, c: bar island below the Keji Bypass.

3. METHODS

3.1 Habitat classification

Aquatic habitats in the study area were classified into three types: riffle, wando, and pond (after Choi et al., 2012). Riffle is a lotic habitat composed of slow riffle and rapid. Wando is a lentic habitat connected to the main channel, composed of bar head-, bar middle-, and bar tail-wando according to its location in a bar. Pond is a lentic habitat disconnected to the main channel, composed of terrace pond and active pond. A total of 27 habitats were surveyed including 20 ponds, 4 wandos and 3 riffles shown in Table 1.

Table 1 List of aquatic habitats surveyed in this study. Locations a, b and c correspond to those in Fig. 2.

2021(n=27) riffle=3, wando=4, pond=17+3		
Site	type	Location
P1	pond	a, terrace
P2	pond	a, terrace
P3-1,2	pond	a, terrace
P4	pond	a, terrace
P5	pond	a, terrace
P6-1,2	pond	a, terrace
P7	pond	b, bar
P8-1,2	pond	b, bar
P9	pond	b, bar
P10	pond	b, bar
P11	pond	b, terrace side
P12	pond	b, terrace side
P13	pond	b, terrace side
P14	pond	c, bar
P15	pond	c, bar
P16	pond	c, bar
P17	pond	c, bar
R1	riffle	a, terrace side
R2	riffle	b, slow
R3	riffle	c, bar head
W1	wando	a, terrace side
W2	wando	b, bar tail
W4	wando	c, bar mid
W5	wando	c, bar mid

3.2 Measurement of environmental factors

A set of following water quality parameters were measured once at each habitat before benthic animal sample collection: *i.e.*, water temperature and pH using D-71S (HORIBA), electric conductivity (EC) using ES-71 (HORIBA), dissolved oxygen (DO) using HQ30d (HACH), and turbidity using TB-31 (TOADDK). The maximum water depth was also measured at each habitat.

Sediment samples were collected at each study site (except rock substrate). The grain size distribution was analyzed in the laboratory using the Testing Sieve of 63um, 125um, 250um, 500um, 1mm, 2mm, 4mm, 8mm, 16mm and 31.5mm in mesh size (Tokyo Screen COLTD, Japan).

Riverbed elevation was measured at each habitat using a power level (SDL30 6399; SOKKIA, Japan). The nearest bench marks of the Yodo River Bureau (on the levee at 49.0Kp and 47.2Kp) to the survey area were used for setting the true elevations. An elevation of the lowest point along the habitat's edge was measured and was assumed as the habitat elevation.

Relative height, defined by the difference between pond's elevation and annual normal water level at the site in the year. Normal water level elevation was simulated by the 1D flow model of the Uji River in 2018 using HECRAC 6.1 (The Hydrologic Engineering Center, CEIWR-HEC). In this study, elevation of each pond habitat was assumed to be equal during 2018-2021. Based on the historical water level data, annual inundation period and frequency was estimated for each pond habitat.

3.3 Biological survey

Aquatic animals including fishes and macro-invertebrates were collected using a hand net with mesh size of 500um from all the types of microhabitats at each sampling site for 5 minutes by two persons. The microhabitats were composed of submerged plant vegetation, root mat, woody debris and aquatic plants, stony riffles, stony shore areas, sandy substrata, and muddy substrata. In case of terrace ponds with submerged plant vegetation along the shores, the muddy substrata and submerged plant vegetation were sampled separately. All the benthic animal samples were collected preserved in 90% alcohol after collection in the field.

Aquatic animal samples were separated into two fractions by filtering using sieves with 500 um and 1mm in mesh size. For both fractions all the macroinvertebrate and fish specimens were identified to the lowest taxonomic level possible using the binocular and microscopes. The following taxonomic keys were used for fishes (Kawanabe and Mizuno, 2001), planarians (Kawakatsu et al, 2007), Amphipoda (Kaneda et al, 2007), Decapoda (Toyoda and Seki, 2014), freshwater benthic animals in general (Ueno, 1973), aquatic insects in general (Kawai & Tanida 2005; Merrit et al. 2008), Diptera (McAlpine, 1981), and Chironomidae (Wiederholm, 1983). The number of individuals for each taxonomic group was counted using the binocular and microscopes.

Based on the aquatic animal data, characteristics of community structure was analyzed using taxonomic richness, total individual abundance, and Shannon diversity index (H') (Spellerberg and Peter, 2003). Shannon diversity index is given by the formula below:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

where pi is the proportion of individuals belonging to the i-th taxon in the data.

3.4 Statistical analyses

All the statistical tests were conducted using R software (version 4.1.2; R Development Core Team 2008). Environmental characteristics of study sites were analyzed using PCA (Principal Component Analysis). Relations of the community parameters to environmental factors were analyzed using correlation analysis, NMDS (Nonmetric MultiDimensional Scaling), RDA (Redundancy Analysis), and CCA (Canonical Correspondence Analysis).

3.5 Habitat potential evaluation

Evaluation of lentic habitat potential was made based on interrelationships among the species richness of benthic animal communities, FVSI (Floodplain vertical shape index), perimeter length and underground clay layer distribution. Historical changes in FVSI and perimeter length were estimated in the 38.9-50.5kp in the Uji River. Water level simulation (1D flow simulation of the Uji River in 2018 using HECRAC 6.1) results were applied for calculation of the FVSI and perimeter length also. Longitudinal distribution of underground substrata of clay layers was detected based on the open-source data of the geologic column (web site "Kunijiban" (28thMarch, 2008)) along the Uji River. The elevation of the underground clay layer surface was used for evaluation of the suitable elevation to create the pond habitats on the banksides.

3.6 Proposal of target image of artificial lentic habitats

Based on the results of lentic habitat potential elevation at different segments, potential sites and desirable elevation for creating artificial lentic habitats were proposed along the Uji River.

4. RESULTS and DISSCUTION

4.1 Environmental conditions of habitats

Larger variation in water quality was detected within pond habitats than riffle and wando habitats (Fig. 3). This may be related to larger number of samples from various locations with a wider range of elevations. In spite of that, the pond habitats of P1-P6, locating at the terrace side (Table. 1), were distinctively separated and were related to higher turbidity, higher water temperature, and higher electric conductivity (Fig. 3).

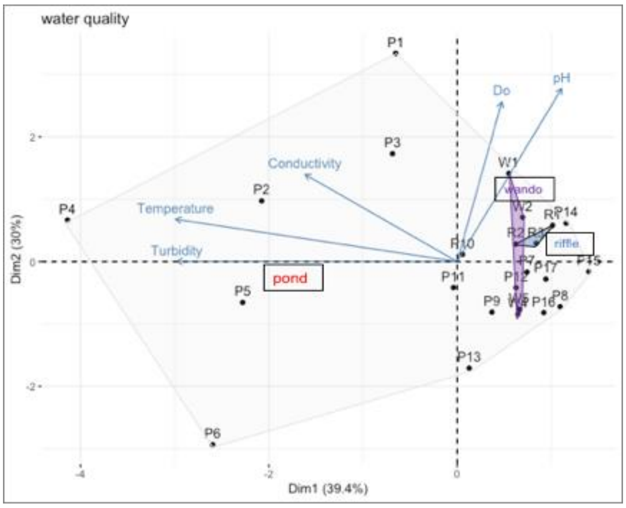

Fig. 3 PCA-biplots of environmental characteristics of the survey sites and three types of habitats based on water quality parameters.

When the relative height and the substrate grain size were included in the physico-chemical parameters of survey sites, results of the PCA analyses showed that the relative height related to the higher turbidity, higher water temperature, and higher electric conductivity charactering the pond habitats P1-P6 (Fig. 4). On the other hands, substrate grain size was negatively related. This means pond habitats with higher relative height apt to be muddy, turbid, warm and dirty environment conditions.

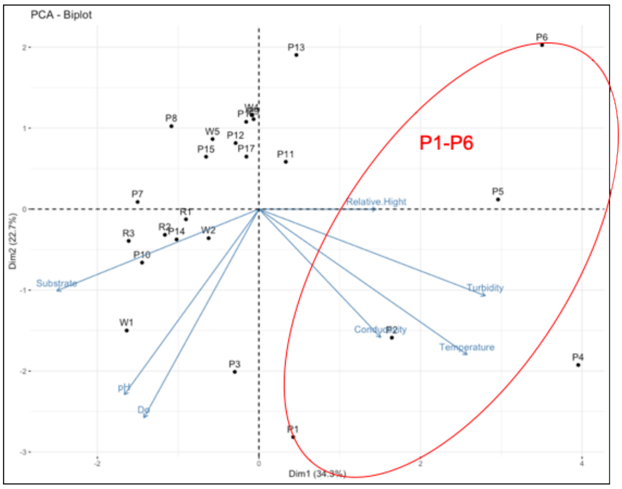

Fig. 4 PCA-biplots of physico-chemical parameters of survey sites with water quality, grain size and relative height parameters.

4.2 Relations of biodiversity to relative height of the ponds

In order to analyze the effect of cross-sectional physical conditions of habitat on benthic animal communities, relations of relative height, inundation period, and inundation frequency to taxonomic richness were tested using correlation and regression analyses. The results showed that taxonomic richness was more strongly related to relative height (R^2=0.7414) (Fig. 5 upper) than to inundation period (R^2=0.4969) and inundation frequency (R^2=0.1548). The Shannon diversity index (H') also was also more related to relative height (R^2=0.4280) (Fig. 5 lower) than to inundation period (R^2=0.2594) and inundation frequency (R^2=0.0411). Therefore, we adopted the relative height as an indicator parameter for analyses of the habitat suitability for benthic animal communities.

Among aquatic animals collected in the samples, aquatic insects were the most both in the taxonomic richness and the abundance particularly in the pond samples. And therefore, the relations of total aquatic insect richness (R^2=0.6959) (Fig. 5 upper left) showed the similar pattern to that of total taxonomic richness.

Within the insect taxa, relations of taxonomic richness to relative height were analyzed for each order of Diptera, Coleoptera, Hemiptera, Odonata, Trichoptera, Ephemeroptera, and Plecoptera separately (Fig. 6). Diptera, Coleoptera and Trichoptera were common in patterns: *i.e.*, they decreased in taxonomic richness in the intermediate Terrace Ponds under the intermediate relative height, whereas increase again in the high island bar ponds under the high relative height conditions.

On the contrary, Hemiptera and Odonata showed rather reverse patterns: i.e., they increased in taxonomic richness in the intermediate Terrace Ponds under the intermediate relative height, whereas decrease again in the high island bar ponds under the high relative height conditions.

And finally, Ephemeoptera and Plecoptera had distinctively different patterns: *i.e.*, they appeared almost exclusively in pond with very low elevation and did not appear at the higher relative height ponds in the island bar. These patterns may be attributable to their adaptation and preference to the lotic environment.

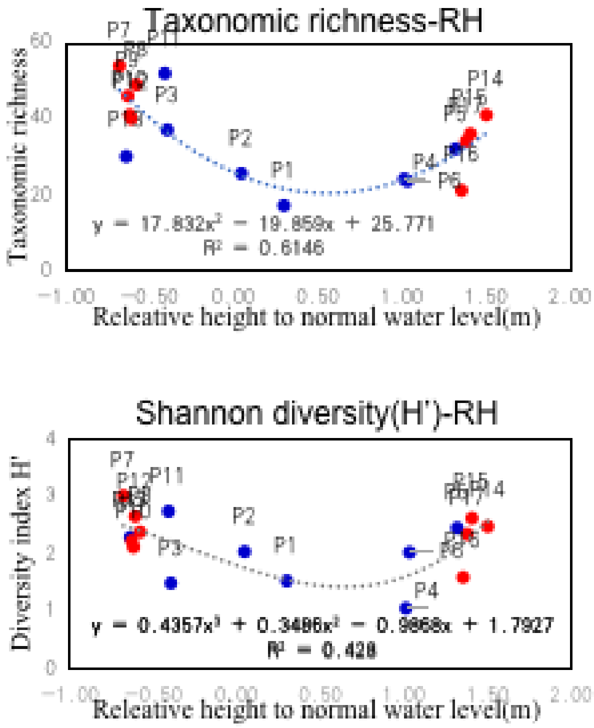

Fig. 5 Relations of taxonomic richness to the relative height distribution of pond habitats

4.3 Relations of bio community structures to relative height of the ponds

Habitat segregation patterns of higher taxonomic groups of the benthic animals were analyzed using NMDS. The results showed that Ephemeroptera, Plecoptrea, Trichoptera, Veneroida (Pisidiidae bivalve), Lumbriculidae and Gobiidae had a high affinity to Riffle and Wand habitats (Fig. 7). This may be related to their lotic habitat preference. On the contrary, Bryozoa, Cyprinodontiformes (*Gambusia affinis*: tap minnow), Hemipera and Nematoda were closely related to terrace ponds with higher relative height. In the other way, Planktonic groups of Cladocera, Ploimida and Cyclopoida were more related to intermediate terrace ponds with intermediate relative height. In addition, Coleopera showed a unique distribution pattern having affinity to high island bar ponds. The others were more related to low terrace ponds and low bar ponds.

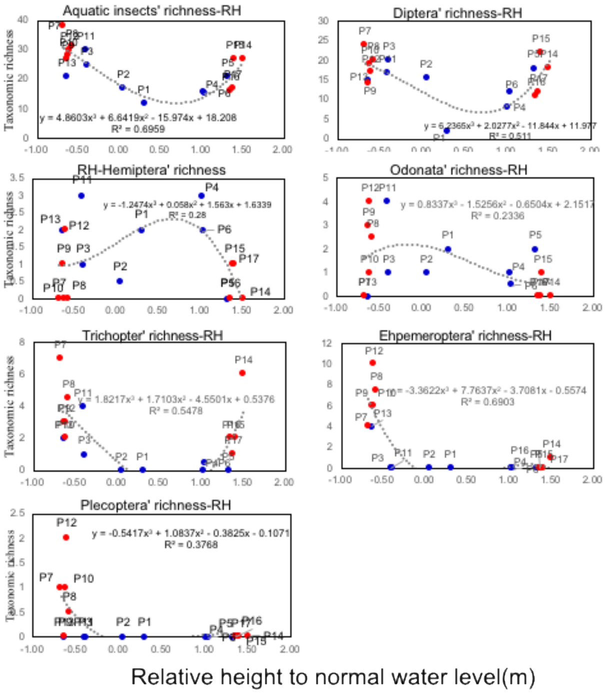

Fig. 6 Relationships of the taxonomic richness to the relative height for aquatic insect groups surveyed in the Uji River in 2018.

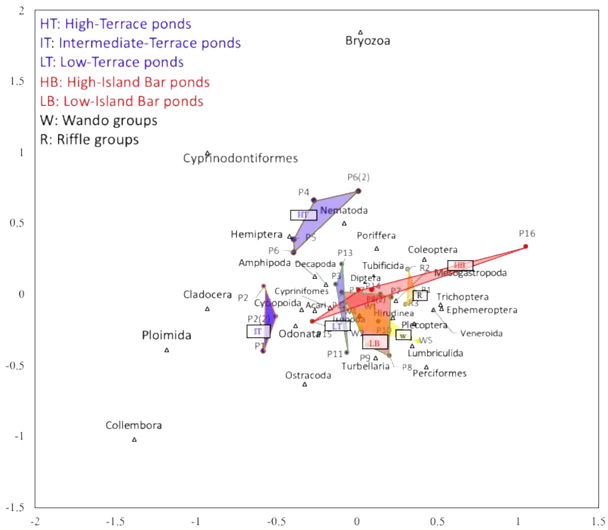

Fig. 7 Results of the NMDS biplots for pond habitats and correspondence of higher taxonomic groups such as phylum and orders. Different symbol colors correspond to habitat types.

4.4 Relations of biological community structures to Environmental parameters

RDA analysis was carried out to analyze the responses of animals of family, genus or species level to environmental factors. Results on dipteran taxa showed a clear dependence on particular environmental factors (Fig. 8). From this biplots, we can conclude that the groups of simulidae, Tanypodinae, *Tvetenia*, *Polypedilum*, *Thienemaniella* were apt to live in riffles, low bar ponds and wando with low relative height, high DO, high pH, and substrates of lager grain size. On the other hand, some dipteran family of Ephydridae, Sciomyzidae, Dolichopodidae, Ceratopogodidae and *Phaenopsectra* preferred to live in wando and high island bar ponds and low terrace pond with high relative height, low DO, low pH, and Fine grain size of the substrates. Interestingly, in different with these environmental clines, Dixidae, *Glyptotendipes* spp. and two species of *Chiromomus* were rather restricted to high terrace ponds depending on high temperature, high turbidity and high electric conductivity. These results indicate that factor of habitat location whether locates on the bar or the bankside is important as well as the relative height.

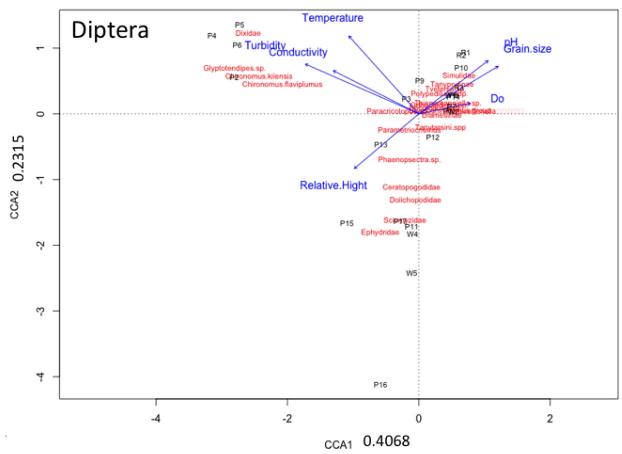

Fig. 8 The results of RDA biplots for all habitat types, environmental parameters, and population abundance of Dipera. Explained proportion of Axis1=0.4068, Axis2=0.2315.

The results of CCA biplots for aquatic insect orders: Ephemeroptera, Odonata, Plecoptera, Trichoptera and Coleoptera showed a bit of different patterns (Fig. 9). Except Libellulidae of Odonata, most of the taxa showed a line distribution on the environmental clines from high relative height, high pH, high DO, high temperature, and larger grain size to low relative height, low pH, low DO, low temperature, and smaller grain size. On these environmental clines, *Teleganopsis puntctisetae* and Hydropsychidae located at the highest end and two species of dragonflies, Calopterygidae

(*Atrocalopteryx atrata*) and Macromiidae (*Macromia amphigena*), and Leptoceridae caddisflies located the lowest end. This result indicated that these taxonomic groups would be a good indicator of relative height.

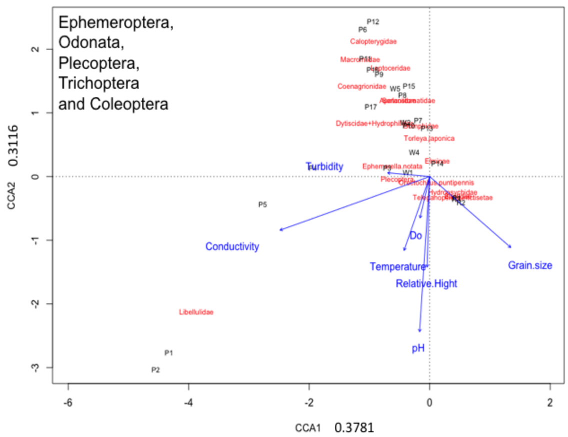

Fig. 9 The results of CCA biplots for all habitat types, environmental parameters, and population abundance of five aquatic insect orders: Ephemeroptera, Odonata, Plecoptera, Trichoptera and Coleoptera. Explained proportion of Axis1=0.3781, Axis2=0.3116.

4.5 Habitat potential evaluation

The lentic habitat potential could be expressed by superposing the perimeter length between normal and high water level, FVSI, and the underground clay layers. The clay layers are necessary for keeping water in the pond habitat particularly on high terrace pond without frequent inundation. Combining with these three factors, distribution of high potential area was exhibited as (Fig. 10). Blue color indicates the area of longer perimeter 1 and 2 with higher potential for ponds of high and intermediate terrace types. Green color indicates the area of smaller FVSI with higher potential for the lentic habitats under the present state of riverbed. Red color indicates the clay strata zones indicate high potential areas for the lentic habitats creation by cutting the terrace. Based on this method we can judge a high lentic habitat potential site suitable for carrying out artificial construction of pond habitats: *e.g.*, A reach with one of these two characteristics had better be modified with cross-sectional geomorphology before the enlargement works of the cross-sectional area.

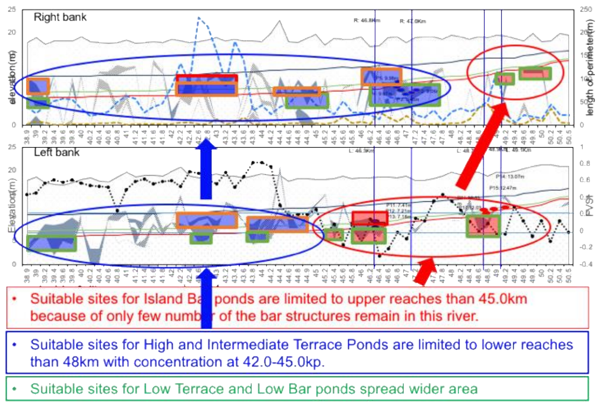

Fig. 10 Longitudinal habitat potential distribution of the in Uji River(38.9Km-50.5Km)

4.6 Proposal of counter measures by artificial habitat creation

In case of the Uji River, it is not easy to improve the lentic habitat potential by the conventional methods such as sediment replenishment (Choi et al., 2018). Therefore, we have to consider any countermeasures by more direct creation of lentic habitats locally. Based on the results of lentic habitat potential in the Uji River shown in Table.2 and Fig. 10, the suitable sites for the local lentic habitat creation were proposed correspondingly. Target image of the lentic habitat creation should be made separately for Island Bar ponds and Terrace Ponds because of their differences in habitat characteristics and ecological functions. The suitable sites for Island Bar ponds were limited to upper reaches than 45.0km because of only few numbers of the bar structures remained in these reaches in this river. The reasons of this restriction might be related to the reverbed reduction reaching the lower elevations than the clay strata and the very hard strata forming the islands were only remained in the reaches with relatively higher riverbed elevations in the whole segment. On the other hand, suitable sites for High and Intermediate Terrace Ponds distributed in a bit longer reaches lower than 48.0km with concentration at 42.0-45.0kp. Suitable sites for Low Terrace and Low Bar ponds spread wider area.

Table 2 Estimated values of FVSI, perimeter2, perimeter1 and lentic habitat potential evaluated for eleven reaches between 38.9kp and 50.5kp in the Uji River.

Reach	FVSI	perimeter2 /m	perimeter1 /m	Lentic habitat potential
38.9-40.0 kp	0.47	4.90	28.36	High potential for HT creation by terrace cutting(L).
40.2-41.0 kp	0.37	5.80	29.85	High potential for HT creation by terrace cutting(L).
41.2-42.0 kp	0.55	3.70	26.57	High potential for LT creation by terrace cutting(R).
42.2-43.0 kp	0.59	6.67	63.18	1. Present high potential for HT(L&R); 2.High potential for HT by terrace cutting(R); High potential for IT&LT by terrace cutting(L).
43.2-44.0 kp	0.66	9.75	53.57	1.Present high potential for HT(L&R); 2.High potential for IT&LT by terrace cutting(R&L).
44.2-45.0 kp	0.17	4.02	42.21	1.Present high potential for HT&IT(L&R); 2.High potential of IT&LT by cutting terrace(L&R).
45.2-46.0 kp	0.06	9.35	35.05	1.Present high potential for HT&IT(L&R); 2.High potential of HT&LT (L) by cutting terrace.
46.2-47.0 kp	-0.08	36.27	45.08	1.Present high potential for HT&IT(L&R); 2.High potential of HT&LT (L) by cutting terrace; 3. Island bar types creation.
47.2-48.0 kp	0.13	4.12	24.23	Present high potential for HT&IT(L&R).
48.2-49.0 kp	-0.18	26.04	81.10	1.Present high potential for HT&IT(L&R); 2.High potential of LT (L&R)by cutting terrace; 3. Island bar types creation.
49.2-50.5 kp	-0.23	9.80	18.79	1.Present high potential for HT&IT(L&R); 2.High potential of LT (R) by cutting terrace; 3. Island bar types creation.

5. CONCLUSION

Longitudinal distribution of lentic habitat potential along the Uji River was estimated based on FVSI, perimeter, clay layer distribution, and their relations to benthic animal communities. This method will be applicable to nature restoration plans for creation of lentic habitats in degraded rivers in general as well as in the Uji River.

6.ACKNOLEDGEMENT

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