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Ecological evaluation of reach scale channel configuration for watershed management

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Abstract

Reach-scale channel configuration (RSCC) such as braided, meandering, wandering or straight channels could be use as target condition in river management of watershed scale. This study aims at revealing relations between hydro-geomorphological RSCC and ecological diversity, and suggests one methods in evaluation of river condition using only aerial photo. The investigation was conducted on the Kizu River located in central Japan, where riverbed degradation and vegetation expansion proceeded after dam construction and sand excavation over a 65-year period. In order to evaluate RSCC, we classified type of aquatic habitat structure as one of the ecological parameters and analysed relations between RSCC and habitat structures/diversity. According to relations RSCC and habitat structures, wandering channel types tended to have higher potential of lentic and lotic habitat quantity and quality than single or braided channel.

Keywords: Reach scale channel configuration, ecological evaluation, aerial photo, habitat structure

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1. Introduction

Information of ecological river condition based on evaluation of ecosystem is essential for river restoration and management. However, ecosystem survey takes a lot of times and labour for covering wide area, and local observed data (especially just fauna or flora) could be difficult to apply for river management in wide/watershed scale. Thus,

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ecological target indices for river management in watershed scale require. Reach-scale channel configuration (RSCC) such as braided, meandering, wandering, or anastomosing and straight channels could be use as target condition. RSCC can be classified by hydraulic-geomorphic parameters such as discharge and slope [1], depth-grain size ratio and width-depth ratio, sediment load and lateral stability [2]. These distinctive relations of RSCC patterns to hydraulic parameters indicate that we could predict changes in RSCC patterns from both empirical and computational data on hydraulic and geomorphic conditions including flow regimes or sediment supply. Therefore, if we could formulate the interrelationships among RSCC, habitat structure and ecological functions, hydro-geomorphic prediction of RSCC could be a powerful device for prediction of changes in a river ecosystem under human impacts on basin environments.

In this study, RSCC was evaluated by habitat structure and diversity as parameter of ecological diversity. Ecological characteristics of streams such as flora and fauna, biodiversity, and productivity are closely related to the reach scale geomorphology [3]. As most stream animals need a set of different habitats in different stages of their life cycles, such as deep-slow for feeding, backwater for resting, and gravel bars for spawning of some fish and invertebrates [4]. Thus, 'habitat heterogeneity hypothesis' [5] states that an increase in the number of habitats and/or an increase in their structural complexity leads to increased species diversity.

This study aims at revealing relations between hydro-geomorphological RSCC and habitat structure, and suggest one methods for evaluation of river condition using only aerial photo. The investigation was conducted on the Kizu River located in central Japan, where riverbed degradation and vegetation expansion proceeded after dam construction and sand excavation over a 65-year period. We classified type of habitats, and analysed relations between RSCC and habitat structures/diversity. And we discuss the appropriate target image of RSCC in terms of habitat structures in the Kizu River.

2. Methods

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. The Kizu River is a typical sandy river by weathered granite mountains in the upper stream, a basin with an area of 1,596 km^2. 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 of the river 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 discharge decreased by about 3,000m^3/s after the dam construction. The annual mean bed-load transported to the lower reach was estimated to be about 183,000m^3/y in the 1960s, but about 23,000 m^3/y in the 2000s. Due to sediment reduction resulting from the dam construction and sand excavation between 1958 and 1963, riverbed degradation was accelerated and has been continued in the lower reach (0 -10 km) until now [6]. In addition, reduction of peak discharge and sediment supply resulted in an expansion of vegetation including wood-land on the active channel and islands as well as on the terrace [7].

2.2. Materials

Aerial photos taken by the Yodogawa River Bureau between 1948 and 2010 were used to examine long-term changes in RSCC and habitat structures in the Kizu River. The orthorectified and georeferenced photos taken in 1948, 1961, 1971, 1979, 1990, 2002 and 2010 were compiled and overlaid sequentially using ArcView (Version 10, ESRI). We divided the study area into 2 km units according to the mean wavelength of meandering channels (mean wavelength: 1.93 km, range: 1.6-2.6 km).

2.3. Reach-scale geomorphic parameters

RSCC types were classified by [8] were used to show conditions of the Kizu River (26 km: No. 0 ~No. 26) (Table 1). RSCC types were classified using two geomorphic parameters (number of channels and sinuosity). Those types were specifically divided into single, slightly wandering (SW), quite wandering (QW), bifurcated wandering

(BW) and braided channel compare to other classification of RSCC such as single, wandering, braided. RSCC of the Kizu River was changed from braided, bifurcated wandering (BW) or quite wandering (QW) channel to slightly wandering (SW) during 60 years (Fig. 1). Channel type was classified per 2 km unit, and thus 13 channel type was shown in year (total study length: 26 km) except 1961.

Table.1. Classification of RSCC based on geomorphic characteristics by [8].

Chann el type		Wandering			
	Single channel	Slightly wandering channel	Quite wandering channel	Bifurcated wandering channel	Braided channel
Image					
Abbr.	Single	SW	QW	BW	Braided

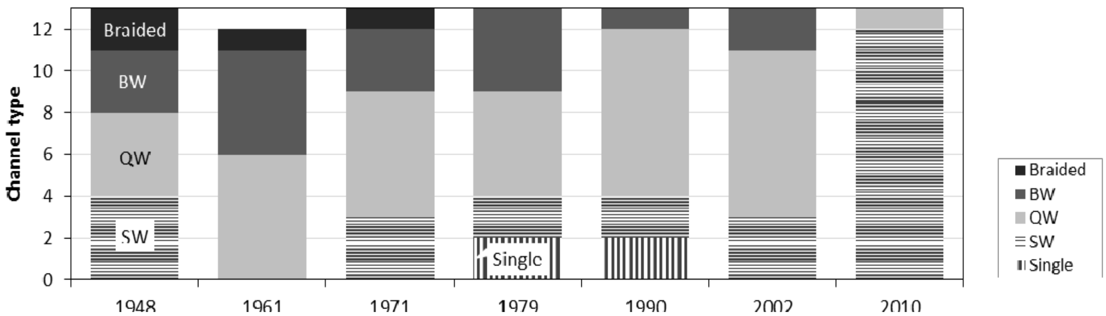

Fig. 1. Historical changes of type of RSCC in the Kizu River from 1948 to 2010.

2.4. Characteristics of aquatic habitat structure

Habitat types were classified into lotic (main slow, secondary slow, gently bending riffle, sharply bending riffle) and lentic (bar-head wando, bar-tail wando, active pond, terrace pond) using aerial photos according to [9]. Main slow was defined as slow flow with smooth water surface located between riffles in the main channel, and secondary slow was slow flow located in secondary channel. According to previous studies on invertebrate communities [10], the angle of riffle flow direction to channel direction influenced the biomass and community compositions. Thus, riffles were divided into two types, gently bending riffle and sharply bending riffle, on the basis of [10]. Gently bending riffle was defined as shallow flow with rough water surface overflowing a lateral bar with bending angle smaller than 30̊ and sharply bending riffle has bending angle larger than 30̊. Wando was defined as lentic water located at the bar opening to the channel; bar-head wando was located at the bar head and bar-tail wando was located at the bar tail. Pond was defined as isolated lentic water; active pond was located on the low floodplain and terrace pond located on the terrace. A total of 8 habitat types were used. We measured the number of each habitat type per 2 km unit.

All aquatic habitats having water-surface in channels and bars were measured. Diversity indices (habitat richness and diversity index) were calculated. The habitat richness was defined as the total number of aquatic habitat types. The habitat diversity index was calculated using the Shannon-Wiener index (*H*').

$$H' = -\sum_{i=1}^{R} p_i \log p_i \tag{1}$$

Historical changes of habitat structures were compared using one-way ANOVA with a post-hoc test by Turkey-HSD. An α value of 0.05 was used to indicate statistical significance for all tests. Statistical analyses were performed using SPSS software (release 19, SPSS Inc.).

3. Results

Total number of habitats for 8 habitat types were significantly different among channel types (Fig. 2). The total number of habitats tended to increase with channel types from single and SW channels to braided channel. As for the number of each type of habitat, lotic habitats (secondary slow, gentle bending riffle, sharply bending riffle) except for main slow had maximum values in braided channel (Fig. 3a). These habitats tended to increase gradually from single to braided channel. Similarly, bar-head wando and active pond among lentic habitats tended to increase from single to braided channel, while terrace pond tended to decrease (Fig. 3b).

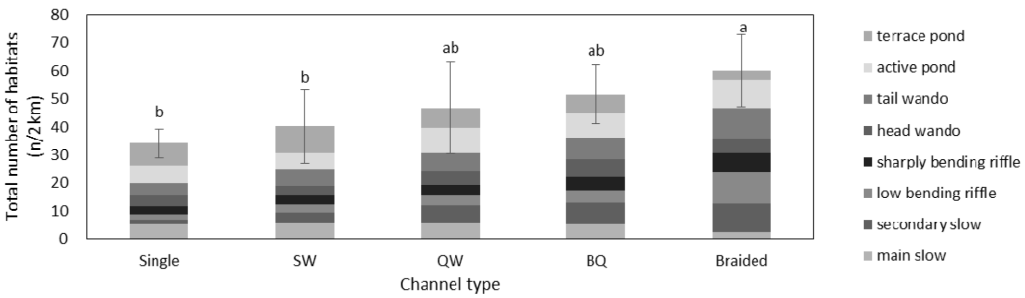

Fig. 2. Relations of total number of habitats (n/2 km) to channel types.

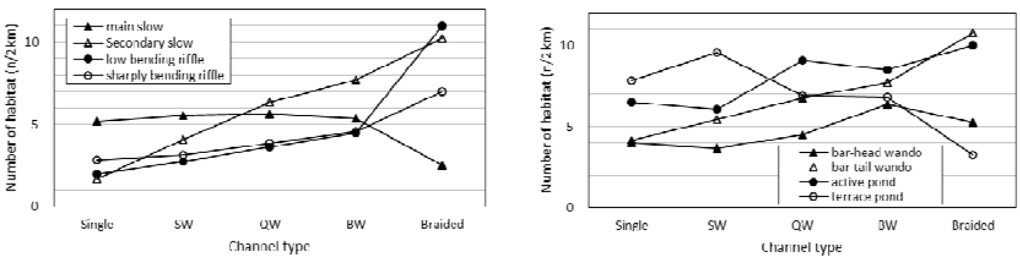

Fig. 3. Relations of (a) average number of lotic habitat and (b) average number of lentic habitat to channel types.

Variations in each habitat index (richness and diversity) were analyzed in relation to 5 channel types (Fig. 4). Habitat richness showed lesser values in braided channel types than in the other channel types (Fig. 4a). Habitat diversity showed not significant difference between channels (Fig. 4b).

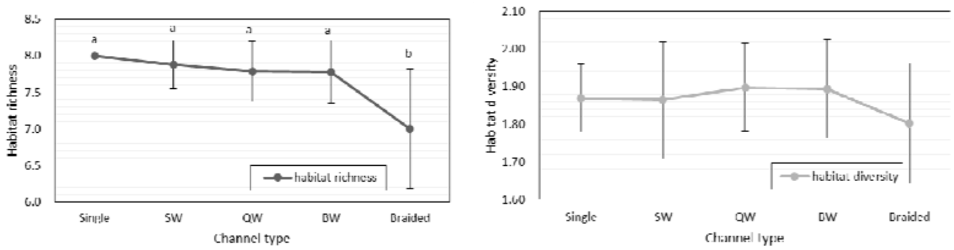

Fig. 4. Relations of (a)habitat richness and (b)habitat diversity to channel types (mean values and SD).

4. Discussion

Our results examined that braided channels were suitable for quantitative total habitats (Fig. 2), on the other hand braided channels had low habitat richness (Fig. 4), especially main slow and terrace pond (Fig. 3). In terms of balance of lotic, lentic habitats and quantitative habitats, wandering channels were more stabilized than single channel or braided channels. However, studies on relations between RSCC and habitat conditions for fish examined the advantages of braided channels. [11] indicated that braided channels were shown to provide more favorable shelter and nursing conditions for fish larvae and juveniles by mitigation of high velocities during floods, by maintaining relatively shallow areas of flow, and by significant adjustments in the thermal regime. [12] examined a braid-like reach, dominated by a wide, dissected midstream bar, which offered three to five times more potential habitat for juveniles in terms of depth and velocity. In this study, braided channel had lower number of main slow and terrace pond than others. In case of the Kizu River, lotic habitats such as riffle and pond has been known as habitat for Ayu fish [7] and invertebrates [10] and bitterlings and unionid mussels (protected species) live in lentic habitats such as pond or wando [13]. Thus, both lotic and lentic habitat should be considered obligatorily in the Kizu River. Abundance of main slow tended to decrease in only braided channels, because braided channels mostly consisted of shallow secondary slow, and terrace ponds located on vegetated terrace tended to have more in slightly wandering or single channels than in braided channels, and thus, habitat richness decreased in braided channels (Fig. 4a). Although braided channels had a lot of riffles and secondary slow, the low potential of riffles in braided channels before the 1970s of the Kizu River was discussed by [10] in terms of quality of habitats. They classified riffle types, and detected that traverse or converge types of riffle (similar to sharply bending riffle) had higher biomass and taxonomic richness of invertebrates than diverge type of riffle (similar to gently bending riffle) by recent field survey. They showed sharply bending riffle had more biomass and richness than gently bending riffle, and gently bending riffle decreased and sharply bending riffle increased during 60 years in the Kizu River. They predicted that invertebrates communities may be increase after the 1970s, and river conditions from the 1980s to the 2010s may have exhibited more biomass and richness than before. On the other hand, although the number of terrace pond increased in single or slightly wandering channels (Fig. 3b), quality of these ponds was also threatened by a low inundation. Reduced connectivity in lentic habitats with the main channel caused habitat deteriorations such as a decrease in the diversity of bitterling and mussels, and the disappearance of representative protected bitterling '*Acheilognathus longipinnis*' [7]. Therefore, intermediate channel conditions between braided channel and single channels was considered as suitable in terms of habitat quality. Consequently, previous channel types than current channel types, but not braided channel, may have high potential of lentic and lotic habitat quantity and quality.

The historical changes of the Kizu River indicated that lateral stability significantly and continuously increased after dam construction and sand excavation. Reduction of sediment supply and stabilized flow may cause variations in the geomorphic characteristics such as terrestrialisation of the vegetation [14]. In order to increase disturbance of downstream of dam and water capacity in dam reservior, comprehensive sediment management in basin scale has been developed in Japan and worldwide, e.g. 'sediment replenishment,' 'sediment bypassing tunnel,' 'flood mitigation dam' without impoundment and dam removal [15]. Among various methods, the Kizu River basin had tested the sediment replenishment activities in the Nunome River below Nunome Dam (since 2004), in the Uda River below the Murou Dam (2006), and Hinachi Dam (2008) and Shorenji Dam (2009) [16]. However, application still require a systematic development in the stage of planning and implementation such as prediction of flushing flows (magnitude, frequency and timing) or determining quantity and quality of sediment [17]. Our results can suggest target restoration period or target river geomorphology. For example, river conditions from 1960s to 2000s or channel types of quite wandering or bifurcated wandering channel could be suggested for river management or restoration project.

5. Conclusion

This study aimed to understand relations between habitat structures and RSCC using historical aerial data. According to relations RSCC and habitat structures, braided channel have a lot of habitats such as riffles, slows, bar-tail wando and active pond, whereas abundance of terrace pond or main slow significantly decreased. Thus, wandering channel types such as quite or bifurcated channel may have high potential of lentic and lotic habitat quantity and quality. These conditions can be helpfully used to suppose target conditions for ecological river management in the Kizu River.

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