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Estimation of Habitat Potential for Ayu Fish by Analyzing Riffle Geomorphology in the Yodo River System

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Synopsis

Riffle is an important habitat for various lotic animals and its geomorphic variations bear the faunal biodiversity in stream ecosystems. In the present paper, we classified the riffle geomorphology and estimated the habitat potential for Ayu fish, *Plecoglossus altivelis* (Osmeridae) in the Kizu, Uji, Katsura and Kamo River, in the Yodo River System. Riffle geomorphology was classified into five types based only on plan view pictures: *i.e.*, Traverse type, Widely Diverge type, Narrowly Diverge type, Converge type and Artificial type. Composition and abundance of theses riffle types were distinctively different among the four rivers. Based on these differences, the potential population of Ayu fish was estimated to be 526131 in Katsura River, 688,795 in Kizu River, 176,365 in Kamo River, and 356,005 in Uji River.

Keywords: riffle, geomorphology, habitat potential, *Plecoglossus altivelis*

1 Introduction

1.1 Background

Many rivers in developed countries have been under various human impacts such as channelization, straightening and confinement by sediment control works and dam construction. These river channel alternations have led to deterioration of biological habitats. The ecological sustainable management is desirable in rivers, and this management requires the suitable methods for assess the river situations. Thomson et al said quantity and quality of habitats are critical elements of ecological conditions to develop methods for environmental assessment and to identify an appropriate target image (Thomson, et al., 2001). Thus, methodological development of habitat qualification is feasible for the assessment and prediction of river ecosystem. Tamai (2004) also mentioned that quantification of habitat suitability is the important task for river environmental management.

1.2 Importance of riffle as habitat

Aquatic habitats in rivers have been classified into riffle, pool, backwater, secondary channel etc. and different geomorphic habitats may serve for feeding (deep-slow), resting (backwater), or spawning (gravel bars) for fish and invertebrates (Takemon, 2007). Riffles tend to support higher species diversity and biomass of benthic invertebrates than the others, and thus are important as food-producing areas for fishes. Riffles are also important as spawning sites as well for fishes such as Ayu fish, *Plecoglossus altivelis* and Dark chub, *Nipponocypris temmincki* (Mizuno et al. 1958; Katano, 1990; Gordon et al., 2004). Thus, Nakajima, el al. (2011) examined that riffles with gravel bed deposited in relatively recent time were the suitable for spawning redd of Ayu fish. Kobayashi et al. (2011) evaluated invertebrate habitat suitability by historical changes of riffle types using aerial photos and field survey data.

1.3 Estimation of Ayu fish abundance per habitat types

Relations of Ayu fish density to stream habitat structures were investigated by various researchers. Takahashi, et al. (2009) reviewed studies on habitat quantification for Ayu fish conducted in various rivers, including his own studies on potential densities of Ayu fish in various types of aquatic habitats (Takahashi and Taniguchi, 2012: Takahashi, et al., 2012). There have been known as the methods multiplying the habitat density estimated from the size of bed rock, from productivity of algae, from the area of each bed morphology in Takatsugawa, and counting the number of Ayu fishes live per unit area at site (Aizawa and Nakagawa, 2008). The common concept of these methods is using an index of potential densities of Ayu fish in the particular habitat type. A total number of Ayu fish in a particular reaches of a river would be possible to be estimated by multiplying total area of habitat types with the Ayu fish density of each habitat type.

1.4 Objectives of this study

Purpose of this study is to quantify abundance of the riffle habitat and other suitable bed morphology for Ayu fish to develop methods for estimation of habitat potential for the fish. In order to achieve the purpose, several riffle types were classified by geomorphic characteristics, and distributions in four rivers of Kizu, Katsura, Kamo, and Uji in the Yodo River basin. Moreover, various geomorphological characteristics within the Yodo River basin were considered as the parameter for determining the development of riffles. The developed method in this study is expected to be adopted for future river management.

Table 1 Hydraulic and physical parameter of the four rivers studied

	Bed slope	Width	Annual max. discharge	Annual sediment discharge
River	%	m	m3/s	m3/year
KIZU 1990	0.00084	184	1600	51325
KIZU 2000	0.00087	160	1600	
KATSURA1990	0.0015	154	840	1961
KATSURA 2000	0.0014	130	840	
KAMO 1990	0.0022	43	200	
KAMO 2000	0.003	46		
UJI 1990	0.0006	102	900	2290
UJI 2000	0.00045	116		

2 Method

2.1 Study site

The study sites were established in four rivers in the Yodo River System (Table 1). The study area of Kizu River located in the lower reaches (0-26 km). The largest flood event occurred in 1953 and reached almost 6,000m3/s. the peak discharge decreased to about 3,000m3/s after the dam construction. The annual mean discharge is about 25m3/s and high discharge is about 43 m3/s. The annual mean sediment transportation to this reach was estimated to be about 100,000 m3/year in the last 30 years. The channel width of the study area was 300–500 m and fine bed materials smaller than 16mm dominated with a mean grain size of 4.27 cm[13)14)]. The length of the sandbar wave was about 2 km (1,848 m). Due to sediment reduction resulting from the dam construction and sand excavation between 1958 and 1963, riverbed degradation was accelerated and had been continued in the lower reach (0 – 10 km) until now (Ashida et al., 2008).

Study site of Katsura River was established in the lower reaches (0 - 18 km). The largest flood event occurred in 1953 and reached almost 2,700m3/s, whereas intensity of peak discharge decreased by 2,400 m3/s after dam construction[15)]. The annual mean discharge is about 30 m3/s and high discharge is about 45 m3/s [16)]. The annual mean sediment discharge to this study site was estimated to be about 1,961m3/year. The channel width of the study area was 300 – 400 m and relatively coarse bed materials (> 16 mm) dominated with a mean grain size of 20 mm[17)]. The length of the sandbar wave was about 1.5 km (1662 m). After Segi dam was constructed in the upstream, 1940, downstream side (0 – 12 km) continue to occur river bed degradation, on the other hand, upper part (12 – 18 km) was in a trend of river bed aggradation, and bed material in the middle part (7 – 12 km) were coarsened.

For Kamo river study was conducted in the range of 13 km from Kamo-ohashi-bridge to Hazukashibashi-bridge. The largest flood event occurred in 1959 and reached almost 715 m3/s[18)]. The annual mean discharge is about 5 m3/s [19)]. The channel width of the study site was about 50 m and the length of sandbar wave was about 500 m (549 m).

At last, the study site of Uji River was set in the lower reaches 0 - 14 km, from the point where Katsura, Kizu, and Uji River join to KEIJI BY-PASS. The largest flood event occurred in 1953 and reached about 1,780 m3/s. The annual mean discharge is about 137 m3/s and high discharge is 189m3/s. The annual sediment discharge in the study site was estimated to be about 2,290m3/year[17]. The channel width of the study area was about 100 m. riverbed degradation has been lasting continuing for a long time and bed materials is in a trend of coarsening. The channel width was about 100 m (102 m) and the sandbar wave length was about 1 km (1008 m).

2.2 Materials and Methods

Aerial photos of the study sites in 1990 and 2000 were used and processed into digital data using Arc GIS version 10.1. After that, riffle area, water surface area of rivers, channel width, and sandbar length which is rounded to the nearest to the whole number for simplification. In addition each river was divided into units based on the sand bar wave length of each river reaches, in order to compare not only within rivers but also among rivers. It enables to compare them in a standardized condition for several hydraulic parameter like water discharge. Values of hydraulic or physical parameters of rivers, water discharge, channel slope, and sediment discharge were cited from the data published by Ministry of Land, Infrastructure, and Transportation and Tourism[17]. For estimation of the amount of Ayu fish, the mean density for each bed morphology was set based on previous studies[9)10)11)]. Takahashi classified bed morphology into 6 types, rapid riffle, flat riffle, pool, A, and B and below dykes, and estimated the value of habitat density as shown in left half of Table.2[12)]. In this study more detailed classification for riffle types were defined and the habitat density for those types as shown in the right half of Table 2.

Table 2 Habitat density of previous studies and the value for use habitat suitability estimation

	habitat density			Present study		
morphology	2009 Takatsu riv.	2012Gohnokawa riv.	1970sGohnokawa riv.	Max.	Mean	Min.
converge	2	1.2	2	2	1.9	1.2
traverse				1.8	1.7	1.1
wide diverge				1.7	1.4	1
narrow diverge	1	0.9	1.5	1.5	1.2	0.9
slowA	1.7	0.8	1.5	1.7	1.3	0.8
pool	0.7	0.5	0.8	0.8	0.67	0.5
slowB	0.3	0.1	0.5	0.5	0.3	0.1
below weir	0.3			0.3	0.3	0.3

2.3 Classification of riffle

Kobayashi & Takemon (2013) classified riffles into 4 types by geomorphic characteristics, wide diverge, narrow diverge, traverse, and converge, and defined them according to Kobayashi & Takemon (2013)(Fig.1). Riffles of wide diverge type cross the bar front diagonally or in a nearly parallel angle and diverge, in addition, development of the bar front is not obvious. Narrow diverge types also cross the bar front diagonally or nearly parallel. Comparing to the former, this type is less diverged and the development of the bar front is strong. Riffles of traverse type cross the bar front by nearly right angles or similar angles and the flow width is wider. Riffles of converge type cross the bar front similarly, and the flow width is narrow in the riffle. The direction of flow changes significantly before crossing the sand bars for traverse and converge types, while it changes little for diverge types. In addition, abrupt decrease in water width is more apparent for traverse and converge types. According to the previous study, types of riffles in this study are defined as follows. Firstly riffles develop near and upstream side of the bar front. Riffles are classified into 5 types, traverse, wide diverge, narrow diverge, converge, and the artificial type. Traverse type is a riffle with the stream line deflected twice sharply where it cross the bar front. In addition water width is wide. The upper boundary is the line where the stream line start to be deflected and the lower boundary is the second place of deflection. Wide diverge (D1) type crossing the sand bar front diagonally or in a nearly parallel with slightly narrowed water width compared to upstream and downstream. Narrow diverge (D2) type is a riffle crossing the sand bar front diagonally or in a nearly parallel manner with well narrowed water width compared to upstream and downstream. For these two types the upper boundary is defined where the channel width gets narrowed compared to the upper stream, and the lower boundary is where the channel width gets wider. Converge type is a riffle with a stream line curved with a narrow channel width. The upper boundary is defined as where the stream line starts to curve and the channel width gets narrowed, on the other hand the lower boundary is where stream line starts to curve to the opposite direction and the channel width gets wider. Artificial type is a riffle developed below dykes constructed for river management.

Pool and slow A was determined based on the relation to riffles. Pool is defined as a part with slow flow developed in downstream of the traverse type riffle and artificial type Slow A is defined as a channel with relatively fast flow, which is developed in downstream of narrow diverge type and riffle developed in downstream of traverse type. And then the rest of the river bed are classified as slow B.

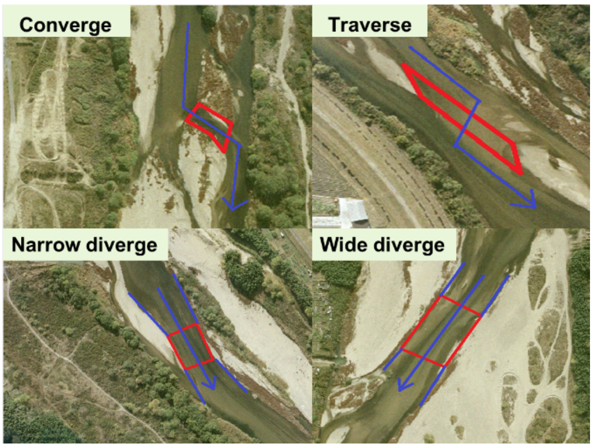

Fig. 1 Examples of the four types of riffles. See text for their definition.

2.4 Analysis

For standardization riffle area ratio was calculated, which is the value of each riffle area divided by the water surface area in each unit. The temporal change of the mean of area ratio in the rivers were investigated and they were compared between those rivers. In addition the difference of area ratio among the units of one of the rivers were investigated with the physical parameters.

3 Results

3.1 Distribution of each riffle type in each rivers

Sandbar wave length of Kizu River was about 2 km (1,843m) therefore the length of unit is 2 km each. Total riffle area of traverse type area reached up to 51,000 ㎡ in the study reaches in 1990. Fig. 2 shows the number of riffles in each unit for Kizu River. In 1990, the number of riffles was 51 in total. Kizu River has the most abundant number of riffles in the four rivers. In some units there were a several riffles, especially unit of 22 - 24km has 5 riffles. A total of 22 riffles of traverse type were counted in almost all units except for 10 to 12km section and 24 to 26km section. Most abundant area for traverse type in Kizu River was 14 to 16km section the riffle area ratio to total section area reaches 0.09, which is the second largest value of all the rivers of this study site, and additionally there were two units of 2 – 4 km and 20 - 22 km, which had large area of traverse type riffles. Wide diverge type also had limited distribution ranged 4 - 8km and 12 - 14km, and 16 - 20km section, compared with other types in Kizu River, the abundance of riffles of wide diverge type was on the low side, but compared with this type of other rivers, it was the largest of all (Fig.2). Wide diverge type was totally about 14,000 ㎡ in 1990 and the maximum value was about 0.026 in the unit of 12 – 14 km. About Narrow diverge type there were no riffles of this type in 12 - 20km sections. Number of riffles was the largest of four rivers and concentrates on 4 - 6km section. The total area of narrow diverge type was about 18,000 ㎡ in 1990 and the maximum value for one unit was 0.048 in the unit of 24 - 26 km. Distribution of converge type is limited in 4 - 6km, 14 - 16km, 18 - 20km, and 22 - 24km sections. This type had no unit in which more than one riffle exists. The total riffle area was about 12,000 ㎡ in 1990. Maximum value of the area ratio of riffle to unit water surface area was about 0.017. Although converge type was less than the other types, upstream part of 18 – 20 km, 22 – 24km section had more riffle area of converge type. On the whole, although all the riffle type abundantly existed, converge type and wide diverge type were relatively scarce distribution, but all the units had plural riffles, so, on the whole, it can be said there were a variety of bed morphology. Compared with the other for rivers', all the type of riffles except for wide diverge type in Kizu River had the largest area ratio to their section area if the four rivers and wide diverge type had the second largest area following Kastura river. It could be thought that Kizu River such kind of riffle abundance and the change in time were caused by the frequent occurrence of sediment transportation.

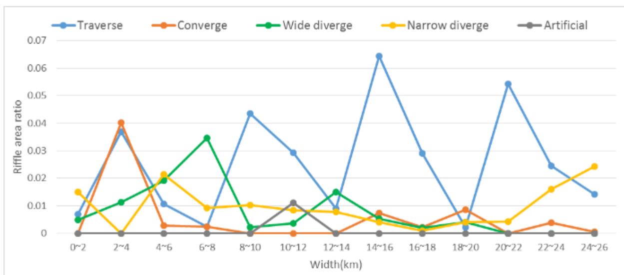

Fig. 2 Longitudinal distribution of riffles in Kizu River

Next, Katsura River had 28 riffles in total, 11 of traverse type, 4 of wide diverge type, 11 of narrow diverge type, and 2 of converge type as shown in Figure 2. In Katura River traverse type riffles had wide distribution although stepping-stonelike empty units existed (1.5 – 4.5km, 7.5 - 9km, 12 - 13.5km, and 16.5 - 18km sections) (Fig. 3). Especially, in each units of 0 - 1.5km, 10.5 - 12km, and 15 – 16.5km there were three or more traverse type riffles. The total area of traverse type riffles was about 11,000 ㎡ in 1990, and the most abundant unit for this type of riffle was the part of 15 – 16.5 km, and its area ratio to water surface area in the unit was about 0.044. For traverse types in Katsura River was the second most abundance in the four rivers. Considering the number of riffle was not small though the ratio was in a small side compared with that type of other rivers, the size of each riffles was small. 5 riffles of wide diverge type were counted, and two of them each were developed in 3 – 4.5km, and 16.5 – 18km units and the other was develop in 10.5 – 12km unit. Furthermore in the unit of 3 - 4.5km there were only wide diverge type riffles. The total area of wide diverge type was about 12,000 ㎡ in 1990, and the most abundance part was the unit of 16.5 - 18 km and the value of area ratio of riffles to unit water surface area was 0.083. For narrow diverge type, totally 4 riffles were developed in 1990. Two of them were in 10.5 – 12 km unit and one of them was in 4.5 – 6km and the other was in 6 – 7.5km. Total area of narrow diverge types was about 7,200 ㎡ of area. The maximum value of the area ratio of riffles to unit water surface was about 0.0028 in the unit of 4.5 – 6 km. Compare with other types, the area of narrow diverge type was small. Moreover the number of them itself was small. The number of converge types were counted up to 9 riffles. Three of them were located in 0 - 3km section and the other in 13.5 - 16.5km section, respectively. Converge type had totally about 10,000 ㎡ in 1990 and the maximum value of area ratio of riffles to unit water surface was about 0.016 in the unit of 1.5 – 3 km. Opposed to such abundance of upper part and bottom part, there were no riffles in the middle part of the river (3 – 13.5km). Compare with the other rivers, Katsura River could be mentioned that abundant distribution of wide diverge types and converge type and scarce distribution of narrow diverge types were characteristic, and upper and lower reaches of the river had relatively various types of riffles compared to the middle reaches. This might be caused by the formation of backwater in the upstream of the weirs. The most abundant unit for each riffle types was located either the bottom part (0 - 3 km) or upper part (15 – 18 km), it could be said there was a deviation in riffle distribution.

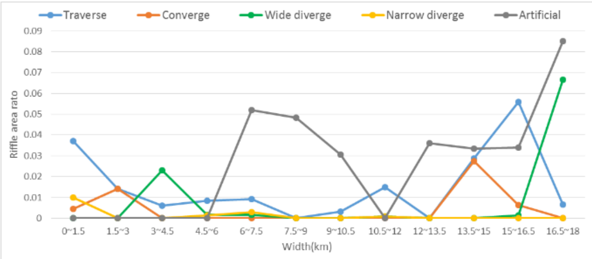

Fig. 3 Longitudinal distribution of riffles in Katsura River

In the Kamo River there were many weirs. Numbers of riffles of each type were not so many: i.e., 8 riffles of traverse type, 2 of wide diverge type, 2 of narrow diverge type, and 3 of converge type in 1990. For traverse type riffles were concentrated in 5 – 7.5 km section, and this type dominated in Kamo River (Fig. 4). total area of traverse type riffles was 4,000 ㎡ in 1990, and the maximum ratio of riffle area to the water surface area in the unit reached up to 0.1 in 5.5 – 6 km reaches. This was the largest value in all the study area. One each of wide diverge type was developed in 3 – 3.5 km unit and 7 – 7.5 km unit. Wide diverge type was totally about 750 ㎡ in 1990. The maximum value of riffle area ratio to the unit water surface was about 0.031, whose location was in the unit of 3 - 3.5 km. Similarly one each of narrow diverge type was developed in 0 – 0.5 km unit and 11 -11.5 km unit. Total area of narrow diverge type was about 550 ㎡ in total (1990). The riffle density was the most in 0 – 0.5 km section, and the ratio of riffle area to water surface area was 0.045. For converge type were developed in 2.5-4 and 4 – 4.5 km units. There was only a few riffles of converge type, whose area was at most 500 ㎡ in 1990, but the peak value of the area ratio to the water surface area in the unit through the study reaches was about 0.031 in the unit of 3.5 – 5 km. As a whole Kamo River had biased distribution. Traverse types and converge types were concentrated in the middle reaches of the river. Sections of 0.5 – 2.5 km and 8.5 – 12 km there were almost no riffles other than artificial type. It could be thought the channelization and drop structure effected the formation of riffles. In the Kamo River Overall, Kamo River had a small number of riffles but most of them were large for the water surface of the unit.

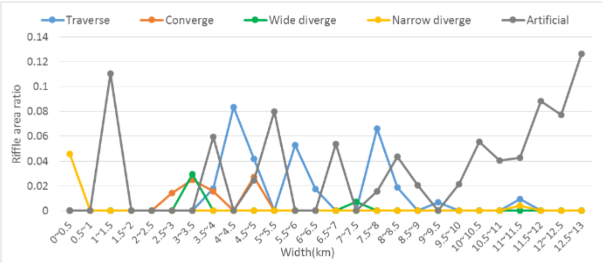

Fig. 4 Longitudinal distribution of riffles in Kamo River

Uji River had the least number of riffles in four rivers. Three of traverse type, three of wide diverge type, and three of narrow diverge type, and two of converge type were counted respectively, but artificial type was not found in this river. In the study site of Uji River, the total riffle area was about 15,000 ㎡. Riffles of traverse type were developed in 6 – 12 km section, and was totally about 4,000 ㎡ and the maximum value of the area ratio of riffles to the water surface in the unit was about 0.021 in the unit of 11 – 12 km (Fig.5). Wide diverge was in 10 - 13 km sections, total area of wide diverge type was about 7,400 ㎡. The peak value of the area ratio of riffles to unit surface was about 0.052 in 12 – 13 km unit. wide diverge type accounted for the largest of total riffle area in Uji River Narrow diverge type existed in 6km, 9 – 10 km, and 12 km sections. The total area of the type was about 2,400 ㎡, and the densest unit of narrow diverge type riffles was 8 – 9 km unit and the area ratio of riffle to water surface was about 0.015. Converge types in 12 – 13 km sections. This type was very slight amount of area, and the largest value of area ratio of riffles to unit water surface was about 0.01.As a whole, it could be said that 12 – 13 km section had abundant riffle distribution and 0 – 5 km section was not the environment suitable for forming riffles. This scarce distribution was thought to be caused by the poor sediment transportation due to dams in the upstream. The character of Uji River was very little amount of riffle for unit water surface area and that there was no riffle in the downstream (0 – 5 km section).

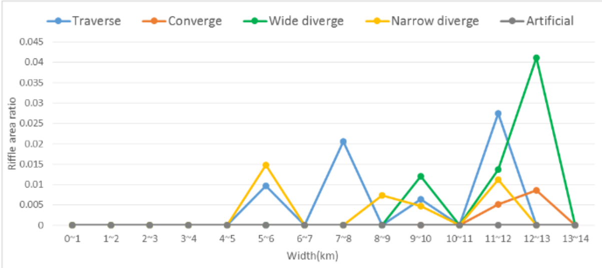

Fig. 5 Longitudinal distribution of riffles in Uji River

3.2 Comparison of distribution of riffle types and their temporal change

Fig.6 shows the mean value of riffle area summed up within a unit divided by the unit water surface area for each river with their standard deviations. Compared with the other rivers, for all the type of riffles except for wide diverge type and artificial type, Kizu river had the largest area ratio to their section area of the four rivers and wide diverge type had the second largest area following Kastura river in 1990. In Katsura River wide diverge types were developed very much compared to that of other rivers. Contrary to that narrow diverge type were slightly developed in the river. In the Kamo River, riffles of traverse types were much developed and those artificial types were also abundant, whereas those of the other types were not developed well. For Uji River the area ratio of riffles are smaller than other rivers. Only wide diverge types were well developed as much as Kizu River. For the other types of the Uji River the area ratios were low. For the secular change the area ratio did not change very much in most of cases. However, area ratio decreased or increased very much in several cases. Converge type in Kamo River increased much and narrow diverge type of Kizu River and converge type in Katsura River oppositely decreased.

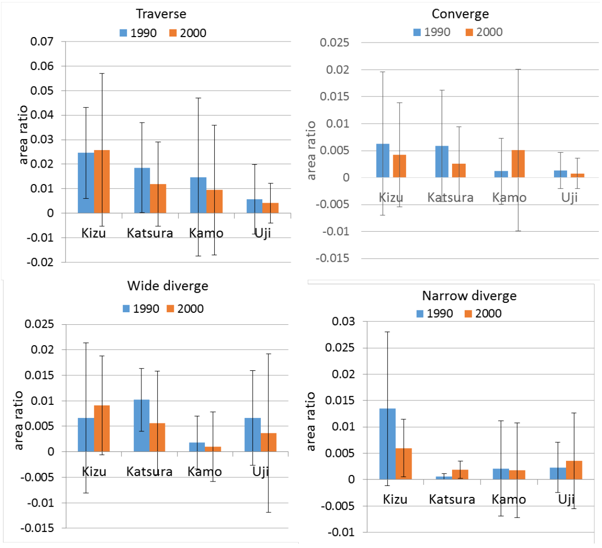

Fig. 6 Comparison of abundance of riffle with rivers

3.3 Relations between riffle types and geomorphological parameters

Fig.7 and 8 show the relations of riffle abundance to the channel width and channel slope. Channel slope had some links to the distribution of area of riffles. For channel width wide diverge type of Kizu River of 1990 and Uji River and converge type of Uji River increased and decreased similarly to the channel width in longitudinal change. For channel slope traverse and narrow diverge type of Kizu River and traverse type of Uji River also increased or decrease similarly to channel slope, although the phase of traverse type of Kizu River was deviated.

Some types of riffles showed a peak value of the riffle area ratio around a particular value of channel width and channel slope, especially those of traverse type and narrow diverge type with channel width, and those of wide diverge type and narrow diverge type for cannel slope. Correlation between channel width and two types of traverse and narrow diverge type was downward convex around 100m of channel width. Moreover the transition of mean area ratio of narrow diverge type in ten years also showed positive correlation especially more than 100 m of channel width. On the other hand, while correlation between area ratio and channel slope of narrow diverge type was upward convex between 0.0015 and 0.002. The transition in time between mean area ratios of narrow diverge showed a little bit similar correlation to it, and for converge type the two comparisons show a similar correlation in the range of more than 0.0008.

It could be said each riffle type had the largest area ratio at a certain channel width and slope. For Katsura River, traverse type was estimated to have the peak area ratio around 180 – 200 m of channel width and 0.0025 – 0.003 of channel slope. Wide and narrow diverge type and converge type were also estimated 100 – 120 m, 170 – 190 m, and 140 – 160 m of channel width and, 0.0025 -0.0027, 0.0001 – 0.0003, and 0.0023 – 0.0025 of channel slope, respectively. The other rivers had the peak value at a similar value of slope other for traverse type and converge type other than Kizu River. Compared with the other rivers, Kizu River had the peak value of area ratio at much more gentle slope then the other rivers. In Kizu River traverse type had the peak around 0.0006 – 0.0008 of the channel slope and converge type is 0.0005 – 0.0007 of channel slope.

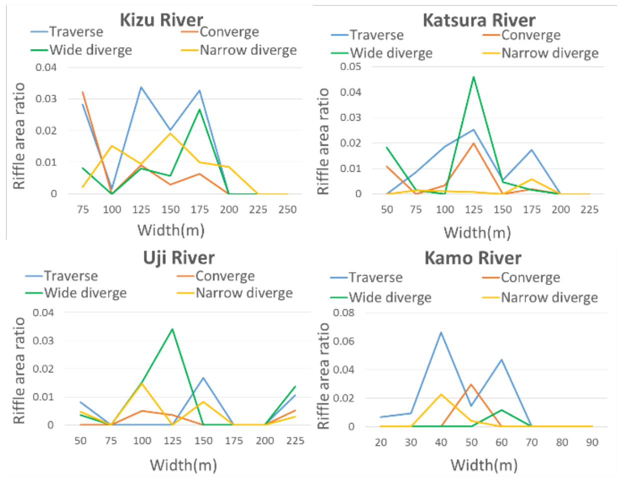

Fig.7 Relations of riffle area ratio to the channel width in the four rivers studied.

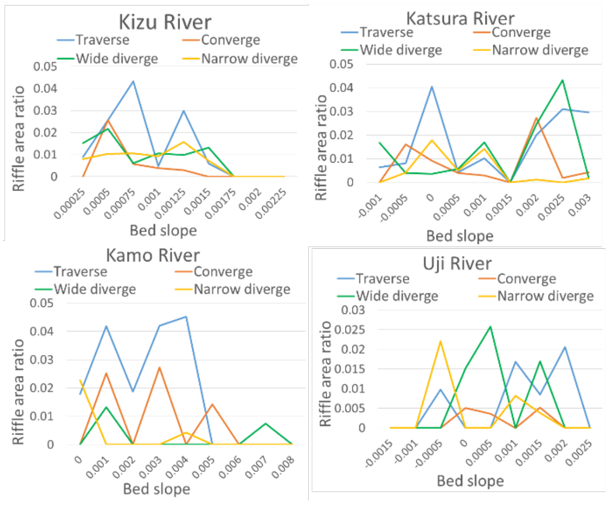

Fig. 8 Relations of riffle area ratio to the bed slope in the four rivers studied.

3.4 Estimating potential of population of Ayu fish

Table 3 and Fig.9 show the estimated potential density of Ayu fish for each river based on the estimated values for each type of habitats. The plotted values indicate the mean of the potential density in two years. Among the four rivers, the Kizu River and the Kamo River had relatively high potential density. But largely it could be said potential densities of those rivers were around 0.35 fishes/㎡. By the way, Takatsugawa and Gohnokawa, which are known as natural rivers are 1.26 and 0.66 fish/m^2. Compared with these values, the habitat potential of each studied rivers are much lower.

Table 3 estimated potential density for habitat suitability of ayu

River	potential density	std
KIZU	0.383953388	0.03864452
KATSURA	0.329683223	0.03793446
KAMO	0.3898586	0.04889701
UJI	0.318730217	0.02516387

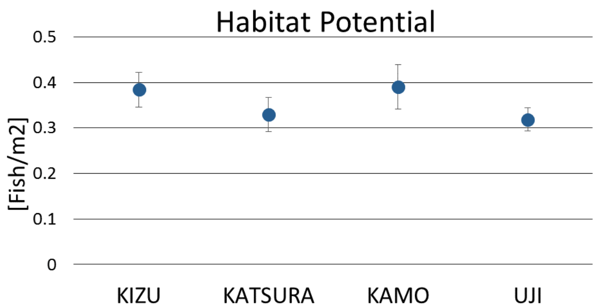

Figure 9 Estimation of habitat suitability in mean value case

4 Discussion

From the result of significant correlations between riffle area ratio and parameters, we can make a proposal of a method for the river management. For better river environment, changing the channel slope and channel width into those to increase the riffle types suitable to Ayu fish. In the case of Katsura River, because the present mean channel width and slope are 154 m and 0.0015, respectively, it can be predicted that decrease channel width and increase bed slope leads to increase traverse and converge types. For Kizu River it is thought that the channel width should be narrowed and the channel slope should be slightly gentler as the habitat for Ayu fish. An example of the specific methods to change those physical parameter may be elimination of weirs in the Katsura River. The elimination of weirs is expected to make the channel slope steeper in the section.

In this study, the abundance of riffles of each type per unit area was related to physical and hydraulic parameters of each river. These interrelationship can be uses for the environmental river management particularly for increasing the potential of population of Ayu fish. In order to apply the method in practical manner, there are still several study subjects remained to be investigated. One is to verifying the riffles definition. Whether the definition of riffle in this study is truly valid for the actual riffles should be confirmed by field survey for actual physical parameter like water depth and maximum bed material size. Another is to verify the validity of potential of population of Ayu fish. Verification work is also needed for this problem because in this study data of other river of previous studies are used. The other is to examine the other parameters contributing to the formation of riffles. In this study correlations to channel width and channel slope were found but only these two parameters did not dominate the determination of riffle development. Therefore further analysis is needed about other hydraulic and physical parameter. Numerical simulation of riverbed evaluation is also required for the validity.

5 Conclusion

Numbers and areas of five type of riffles were estimated for Katsura River, Kizu River, Kamo River and Uji River. Katsura River had many wide diverge and artificial types and few riffles are developed in middle part of the river. In the Kizu River there were the most abundance of riffles, especially traverse type. In the Kamo River traverse type riffles dominates concentrating on middle part of study site. At last in the Uji River there are the least abundance of riffles, especially no riffles in lower part. This is applicable to other organisms than Ayu fish. The potential population of the fish was estimated to be 526131 in Katsura River, 688,795 in Kizu River, 176,365 in Kamo River, and 356,005 in Uji River. However, further consideration and verification will be needed for practical use. Correlation are confirmed between development of riffle and geomorphological parameters, width and bed slope. There seems to be a suitable value for maximization of riffle, however channel width and bed slope are not only the parameters for dominating the formation of riffles.

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