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Estimation of the Suitable Sediment Load for Ayu Fish Habitat in the Kizu River

Koji MISHIMA(1), Tetsuya SUMI , Yasuhiro TAKEMON and Sohei KOBAYASHI

（1）Graduate School of Engineering, Kyoto university

Synopsis

It is necessary to clarify the effect of the change of sediment transportation on environmental condition and maintenance of artificial structure. The environment understanding that agents that change the river bed geomorphology are associated with environmental factors which prescribe the habitat of an organism. Then the purposes are to conduct environmental evaluation based on the suitability for sweet fish habitat in Kizu River, and to estimate two dimensional feature of reproduction habitat used the distribution of piscivorous aquatic birds indirectly, and finally, to estimate the amount of sediment load for creating suitable river bed geomorphology for sweet fish. In order to evaluate river bed geomorphology based on the habitat of sweet fish, to distinguish the suitability of riffles for reproduction habitat and growth habitat because they have different geomorphological characteristics. The most suitable amount of sediment estimated from this approximate curve is 79961 m^3/year, and the riffle area of traverse and converge type is 73004 m^2. Previous environment evaluation is based on past situation. The suitable river management condition have been estimated from the historical comparison in a river focusing on various geomorphological parameter. However, environmental evaluation method in this study enables to evaluate the assumed conditions and compare with various scenarios and even between rivers.

Keywords : Sediment Transportation, Environmental Evaluation, Ayu Fish, Riverbed Geomorphology

1. Introduction

1.1 Background

As natural hazards often bring severe disasters to human society, most of governments have constructed artificial structures, such as check dams and reservoir dam, to prevent sediment and flood disasters. Those artificial structures controlled downstream discharge and change the sediment dynamism situation. As the result of them, downstream artificial structure for flood control are starving sediment and accelerated channel erosion and bank failure. Such the lack of sediment did damaged to habitat diversity and biodiversity. Because a lot of organisms on the earth have adapted to conditions of disturbed habitats, reduction in the frequency and/or intensity of floods has a negative impact on fauna or flora, such as increasing exotic species and causing protected species to disappear. In order to restore the healthy habitats in these rivers, it is necessary to develop river management methods for assessing the ecological conditions of rivers and for linkage between ecological and hydraulic conditions in a hierarchical manner. Therefore, to improve sediment transportation control is a critical issue for better river management. It is necessary to clarify the effect of the change of sediment transportation on environmental condition and maintenance of artificial structure. Government is required to establish the measures for total river management based on those evaluations of the conditions.

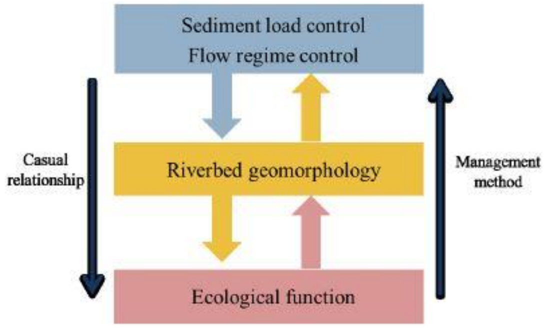

Figure 1 the concept of river management

River bed geomorphology has two facilities, providing habitat for ecosystem and facilitate material circulation. They determine the characteristic of river ecosystem, however, previous river bed geomorphology evaluation methods tend to try to manage and maintain biological function directly because they focused on the amount or the distribution of a certain organism or water quality. In order to ensure the sustainability of growth and inhabitation, no matter how the organisms are secured, the management goal cannot be achieved unless the relation between the habitat and the organisms is regarded as the object of evaluation. The interaction among biological community is also thought to follow the environmental requirement for each habitat. Thus, the management plan focusing on river bed geomorphology is reasonable for river maintenance and management in order to restore a river ecosystem.

1.2 History of Kizu River

Kizu River is a first class river in Yodo River Basin, with 1596 km^2 of catchment area. It comes from Nunohiki Mountain Range, through Ueno Basin and Yamashiro Basin joining Takushoku and Hattori River, and it also come from Nunohiki mountain range through Nabari Basin joining Nabari River to Kasagi Gorge. Then those two river confluent and flow north-westward to the confluence point with Uji and Katsura River at Yahata located in southern part of Kyoto Prefecture. It continues to Yodo River. It is mountain stream between the source of the river and 4 km downstream point from Kamo, and it changes into alluvial-land river from the downstream point of Kamo.

Bed material is dominated by sand material in Kizu river basin because weathered granite is dominated in geological component of the upstream mountains[6]. Abundant sediment supply forms various bed geomorphology. Supplied sediment deposits lower 25 km section from the confluence point where river width is wide and bed slope is gentle[7].

Kizu River had formed great range of flood plain until embankment in 1630s by the government at that time. After that Kizu River has been altered for flood control, irrigation, and resource, for example, excessive logging forest on mountain upper reaches, gravel mining, construction of dams, weirs, and check dams, river channel dredging construction, and enacting River Law. They had a significant effect on river bed aggradation and degradation in Kizu River, and the excessive riverbed changes caused social and environmental problems: i.e., aggradation lead to increase of flood risk, and to decrease of biodiversity due to excessive disturbance frequency in the channel. On the other hand, river bed degradation lead to vegetation expansion, scouring upstream side of bridge pier, bank failure as social problems and reduction of habitat diversity as an environmental problem.

As a historical change, river bed aggradation had occurred until 1960s, when Takayama dam is constructed in the upper stream. After dam construction, river bed degradation has been occurred due to the reduction of sediment transportation from the upstream. Other sediment control work also contributed to it. River bed degradation is significant in the upper reach and lower reach as a present situation. Also, vegetation seriously developed compared with the situation before 1960. The bare land are becomes as half much as Flood control works by dams in the upper reach stabilize sandbars, and the gaps are developed between channel and floodplain[8]. Sandbar pattern is also changed. Once, variety of channel types due to large amount of sediment load, however alternate bar has been developed due to bed degradation and stabilization of channel by vegetation in recent years[9][10].

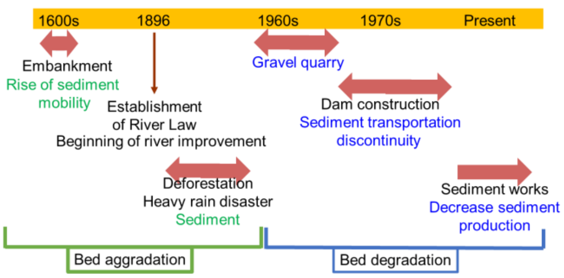

Figure 2 Chronology of event in Kizu River

1.3 The development of environmental evaluation method

HEP is all known as the method of environmental evaluation based on geomorphological conditions as a basis of the habitat. It is established method for total evaluation of ecosystems from the viewpoint of suitability for habitat of wildlife. Total evaluation means to evaluate geomorphology by "quality", "space", and "lifespan" as a habitat. Quality is suitability for feeding, reproduction, and so on. Space is the area functioning as a habitat. Lifespan is habitat existing duration. HEP is the most commonly used method for natural environment assessment in the U.S. in order to make consensus about project plan and its conversion plan presupposing ‘No Net Loss’. Physical Habitat Simulation Model (PHABSIM) was invented for evaluation of flow velocity, water depth and bed material, and put into practical use by Instream Flow Incremental Methodology (IFIM) for setting normal flow discharge.

HEP and PHABSIM enable the validity of countermeasures to be investigated by numerical evaluation of plural object area or project effect using suitability of important environmental factor for the object organism using Habitat Suitability Index (HSI).

Also, evaluation method for current situation of environment including from the community characteristic to river bed geomorphology has been developed. For example, River Invertebrate Prediction And Classification System (RIVPACS) invented in UK, and Index of Biotic Integrity is put into practical use in various country in Europe and America. Especially, RIVPACS enables you to anticipate the change of invertebrate community by multi-variable analysis in the case of that river classification based on invertebrate community and environmental condition, and is utilized to anticipate the main composition of invertebrate community and artificial impact in 614 points of rivers in United Kingdom. In japan, Ministry of Land, Infrastructure and Transport (MLIT) accumulates invertebrate community data of 109 of first class rivers in five years. However, the method to utilize those information for the evaluation of impact on environment has not been established yet. In order to achieve Japanese RIVPACS using them, the subject that integration of invertebrate community classification criteria, accumulating corresponding data for environmental condition, adding data of river branches and intermediate and small rivers, and so on.

Each of environmental evaluation methods introduced above is useful for evaluating present suitability and detecting needs of environmental improvement, however, has a difficulty to present environment countermeasure. The reason of the difficulty is weak relation to the change of river bed environment due to handling environmental factor at survey point of species or organism communities separately. In order to overcome such a fault of past environmental evaluation method, the environment understanding that agents that change the river bed geomorphology are associated with environmental factors which prescribe the habitat of an organism.

1.4 Sweet fish

Sweet fish (*Plecoglossus altivelis*) is an amphidromous fish, which is familiar with Japanese people for fishery and recreation. In addition to fishery, mariculture is also conducted. Sweet fish is one of the important water resource for freshwater business. However, sweet fish in Japan has been decreasing since around 1970s as shown in the Figure.4. The reasons for such a drop of sweet fish catchment are thought divided habitat, reduce of flow volume, cold water disease, excessive expansion of seed release, and discontinuity of sediment transportation. Discontinuity of sediment transportation due to the artificial structures like dams made downstream bed morphology suitable for sweet fish shrink. Sweet fish continues to next generation in one year. Larva hatch from the egg around November, and then they flow down to coastal area. They spend winter there feeding plankton. Juveniles swimming upstream to middle reaches in spring and they feed algae attached on stone surface. After growing up to adults, they move downstream and spawn their egg digging up the ground. The point is the characteristics of bed morphology are different between growth habitat and reproduction habitat of sweet fish.

Figure 3 the characteristics of growth and reproduction habitat. Left is bite-mark of sweet fish algae on large stone with clean surface. Right is spawning redd, gravel bed

Growth habitat is used as a feeding place for algae attached on stone surface (Figure 3), therefore the environment where algae grows up very much is necessary. The suitable environmental features for growth habitat are clean water, efficient oxygen supply, and relatively shallow riffles where large stones with clean surface deposits on river bed surface. On the other hand, reproduction habitat is studied very much, as the result of them, it is clarified that shallow riffle with fast flow and soft river bed is suitable for reproduction habitat (Figure 3). The importance of softness derives from spawning characteristic that they dig up the sediment when they spawn eggs. It was clarified that such a bed morphology is formed by newly deposited sediment load. Not only these two bed geomorphologies, but also pool is important for the habitat of sweet fish. They take a rest and escape from their natural enemies there.

Figure 4 Historical change of sweet fish production

1.5 Goal of this study

In this study, the purposes are to conduct environmental evaluation based on the suitability for sweet fish habitat in Kizu River, and to estimate two dimensional feature of reproduction habitat used the distribution of piscivorous aquatic birds indirectly, and finally, to estimate the amount of sediment load for creating suitable river bed geomorphology for sweet fish.

2. Method

2.1 Study site

The study site of Kizu River was established in the lower reaches of the Takayama Dam (0 - 44 km). The largest flood event occurred in 1953 up to 6,000m^3/s and 6,100 m^3/s was set to the planned high flow discharge at present. The peak discharge is controlled down to about 3,000m^3/s under the dam operation. The annual mean discharge is about 25m^3/s and high discharge is about 43 m^3/s. The annual mean sediment transportation to this reach was estimated to be about 100,000 m^3/year in 1970s. However, that of recent years has been estimated from 20,000 to 30,000 m^3/s. The channel width of the study area was from 300 to 500 m and fine bed materials smaller than 16mm dominated. Mean grain size of 4.27 cm. The length of the sandbar wave was about 2 km. 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.

2.2 Classification of riffle

In order to evaluate river bed geomorphology based on the habitat of sweet fish in detail, to distinguish the suitability of riffles for reproduction habitat and growth habitat because they have different geomorphological characteristics. Kobayashi and Takemon classified riffles into 4 types by geomorphic characteristics, wide diverge, narrow diverge, traverse, and converge, and defined them as following. 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 change 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 4 types, traverse, wide diverge, narrow diverge, and converge 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 of the riffle is the line where the stream line start to be deflected and the lower boundary is the second place of deflection. Wide diverge (W) type crossing the sand bar front diagonally or in a nearly parallel with slightly narrowed water width compared to upstream and downstream. Narrow diverge (N) 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 smoothly curved with a narrow channel width. The upper boundary is defined as where the stream line starts to curve the channel width gets narrowed and the lower boundary is where stream line starts to curve to the opposite direction and the channel width gets wider. In the previous study, it is clarified that traverse type riffle is suitable for reproduction habitat, and converge type riffle is suitable for growth habitat of sweet fish. This is because the geomorphological characteristic of them determine the river flow. Traverse type riffle is wide and shallow riffle where sediment newly deposited, therefore, river flow is not fast, and then because relatively small bed material remains there without being flushed out soft small river bed is formed where sweet fish easily dig out. Oppositely, converge type riffle is fast river flow because flow converges into narrow channel, therefore only large stones remain there. As a result, large stones where algae grows up are shown in river bed surface. In this study, the historical change of converge and traverse riffle by bed morphological classification using aerial photo in 1990, 2000, and 2014.

The difference in suitability for growth habitat of each riffle type was determined as shown in table 1. Those value were set based on previous study of estimation of optimum capacity of sweet fish in various river[26]. The difference in riffle classification was adjusted considering the each characteristic of flow.

Table 1 Suitability of riffle as a growth habitat

TAKAHASHI						This study		
MORPHOLOGY			2009Takatsu	2012 Gohnd	1970s Gohnd	MAX		min
Riffle	Rapid	Converge	2	1.2	2	2		1.2
	Flat	Traverse	1	0.9	1.5	1.8		1.1
		WIDE Diverge	1	0.9	1.5	1.7		1
		NARROW Diverge	1	0.9	1.5	1.5	~	0.9

2.3 Field survey of piscivorous birds as indirect indicator of sweet fish habitat

The field survey is conducted to confirm the correspondence between riffle and reproduction habitat. This survey is a verification of the relation between the actual reproduction habitat and traverse riffles by measuring the number of piscivorous birds, egrets and great cormorants, gathering at the sweet fish habitat in order to feed. In order to verify the validity for both growth habitat and reproduction habitat, field survey was conducted in the summer term when sweet fish utilize growth habitat and the autumn term when they utilize reproduction habitat.

Field survey was conducted twice on sunny day afternoon in November in 2015 and 2016, and September in 2016, respectively. The number and location of egrets and great cormorants are measured by visual observation from the bank and bridge in 44 km section from confluence point to Takayama dam. The number of piscivorous birds are summed up in each river bed geomorphology.

Figure 5 Egrets

Figure 6 Great cormorant

In order to investigate the relation between feeding birds distribution and actual sweet fish habitat, all the individuals are judged whether they are feeding or not using photo taken at the field survey, and eliminated the individuals taking a rest from the data. The criteria judging whether an individual are feeding or not are defined as follows:

2.3.1) The location of the individual is in the channel or beside the channel

2.3.2) The individual looks at water surface to find sweet fishes or doing predatory activity like diving of great cormorant

2.4 Two dimensional river bed evolution calculation (Nays2DH)

To estimate the suitable amount of sediment transportation for sweet fish habitat from the correlation between the sediment load and development river bed geomorphology, numerical simulation was conducted using Nays2DH, a solver for two dimensional river bed evolution. Also, the verification that the prediction of reproduction habitat distribution can be done is conducted using the correlation the previous chapter.

International River Interface Cooperative (iRIC) is the software for river flow and river bed evolution analysis integrating functions of United States Geological Survey (USGS) and RIC-Nays. In this calculation, Nays2DH solver is used for river bed evolution calculation. It can easily analyze the change of grain size distribution and river bed geomorphology. Advection term finite difference method. Turbulence flow field zero-equation model. Boundary condition of upper and lower boundary is set by upper boundary flow velocity. Initial water surface is calculated by steady flow. Calculation of flow regime and river bed evolution simultaneously, and sediment transport is calculated as only bed load. The calculation of bed load vector is done by Watanabe formula. Lane-Kalinske formula is adopted suspended sediment equation. Following is the equations and formulas used in the model. Following is fundamental equations for each model.

3. Results

3.1 Historical change of riffle

In order to clarify the historical change of river bed geomorphology as a suitable habitat of sweet fish, the riffle distribution analysis was conducted as following. First, the several geometrical information of the rivers, which are the water surface area, the area of each riffle type are calculated using image analysis software. After the calculation of the morphological information, each river was divided into three sections, lower (0 – 8 km), middle (8 – 18 km), and upper (18 – 26 km) reaches. The concept of this division is from migratory characteristic of sweet fish. They migrate upper reaches in growing season and move to downstream in reproduction season. After that the ratio of each types of riffle area within each section. Then, bed geomorphology is classified into 6 groups, 4types of riffle, and pool, and run. The criteria of geomorphology classification using aerial photo are defined as: 1) riffle develops in the front of sand bar and water surface of riffle is choppy water, 2) extracted riffle is classified into 4 types following the classification method, 3) pool develops in downstream of traverse riffle and where river flow collide with river bank, 4) other than above criteria is classified as run. The distribution character through the study site from the viewpoint of riffle types and percentage of riffle area in total water surface area, which is defined as abundance ratio of a riffle type. As the result of the image analysis by the software, distribution of the riffles was calculated as Figures below.

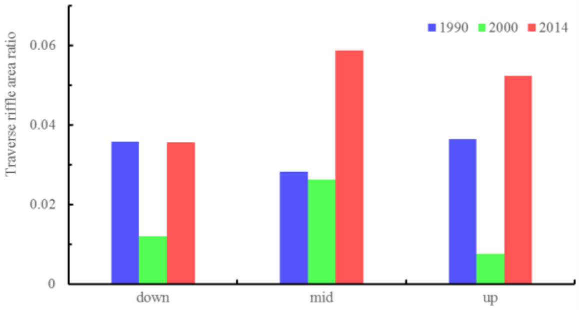

Figure 7 historical change of traverse riffle area

Figure 6 shows the historical change of abundance ratio of traverse riffles for each reach. The abundance of traverse riffle restored from the situation in 2000. For middle and upper reaches, the abundance rate in 2014 is the highest of the three. The reason why the abundance ratio of traverse riffle in 2014 is high in all reaches can be thought to be the typhoon no. 13 in 2013. The active sediment transportation occurred by large scale flood can be thought to increase the abundance rate of traverse riffle. The abundance rate of traverse riffle in 1990 is higher than that in 2000 in all reaches. This can be thought as the difference of the amount of sediment transportation. Oppositely, the abundance rate of converge riffle in 2000 is the highest of the three in all reaches as shown in Figure 7. The abundance of traverse and converge riffles can be thought to conflict as hypothesis from these result.

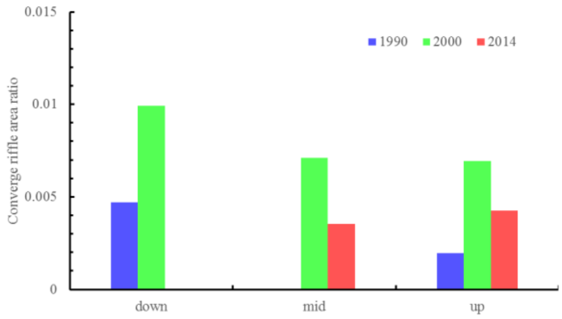

Figure 8 historical change of converge riffle area

3.2 Indirect indicator for sweet fish habitat

Figure 8 shows the result of field survey of the piscivorous bird distribution. Most part of the active piscivorous bird distribution in reproduction season is similar in both year. Summer distribution is different from the autumn pattern. Distribution of birds in autumn is obviously prejudiced by some geomorphological characteristics. The most riffle types in all the riffles where the piscivorous bird was measured was traverse type riffle.

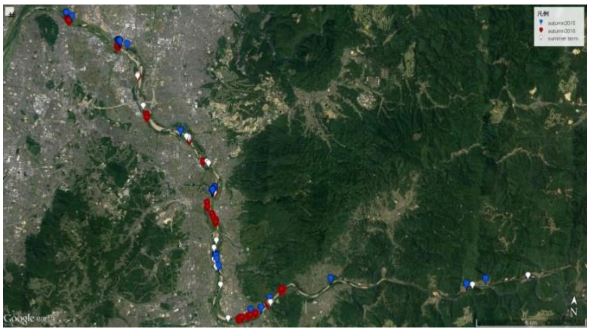

Figure 9 Result of distribution survey of piscivorous birds

Next, a geomorphological characteristic, the aspect ratio of riffle, is defined and measured from image analysis software, and checked correlation with the bird distribution. The aspect ratio of riffle is the proportion of the width to the longitudinal length of riffle. Thus the wider the channel is, the larger the number is. The correlation between the distribution of birds and that geomorphological factor is shown in Figure 9. There is loose positive correlation between those. It means the piscivorous birds tended to feed in traverse riffle in reproduction season, which indicated that the sweet fish utilize traverse riffle as a reproduction habitat because wide channel is the characteristic of traverse riffle.

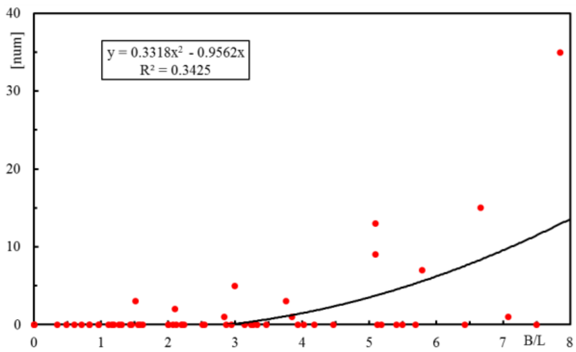

Figure 10 Positive correlation between autumn feeding bird distribution and aspect of riffle

3.3 Reproduction calculation

Two dimensional river bed evolution analysis is conducted using iRIC. Calculation condition is shown in table 2. iRIC can set particle size distribution in total 10 stages at any percentage for any cell. Only bedload is considered as sediment transportation. Calculation grid is set by dividing designated area into any numbers in both of longitudinal and traverse direction. The longitudinal length of a grid is about 20 m and a grid width in channel is about 15 m, and that in bank ranges from 15 m to 70 m. To confirm the accuracy of numerical simulation, calibration is conducted using digital elevation model data sets measured in April, 2009 and November, 2013 in Kizu River. Calculation condition is set as shown in table 1, Particle size distribution measured at centroid of 14 km in 2011 at is adopted. Upper boundary flow regime subject flow volume data measured more than 800 m^3/s at Inooka observation station from April in 2009 to November in 2013 (case F1 shown in Figure 11). Friction coefficient (Manning's coefficient) is set n = 0.022. Turbulent flow model is set as zero-equation turbulence model. Bedload sediment transport is calculated by Ashida-Michiue formula.

Table 2 Calculation condition for reproduction calculation

Boundary Conditions	
Bed Elevation	Measured in April, 2009 and November, 2013
Bed Material	Case 1 shown in Figure 10 to all grids[25)]
Calculation Section	11 km section from 9 km to 20 km from confluence point
Upper Boundary Flow Regime	Case 1 shown in Figure 9 to all grids
Grid Number	Cross Stream : 21 for channel, 5 for each bank / Streamwise : 550
Time Step	0.4 seconds
Manning's Coefficient	n = 0.022
Turbulent Flow Model	Zero-Equation Turbulence Model
Bedload sediment transport	Ashida-Michiue formula

The result is shown in Figure 10. Though the extent of the deposition and erosion is small, the tendency of them is reproduced. The reason why the amount of bed elevation change is much smaller than the actual change can be thought setting of particle size distribution and high threshold of flow regime. Grain size data is measured at centroid of the channel, therefore mean diameter of grain size is larger than the actual value. And flow regime without considering small flood reduces the small grain size sediment transportation.

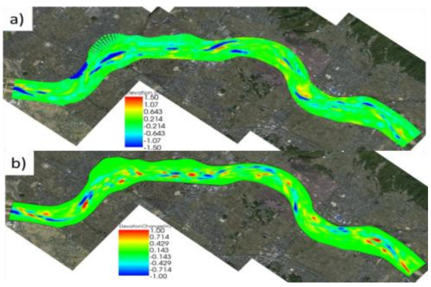

Figure 11 bed elevation change of reproduction calculation a) actual change, b) numerical simulation

After calculation, bed geomorphology classification is conducted to the result of the reproduction calculation. Before the channel is divided into each geomorphologies, water edge have to be determined. In this study, 0.2 m depth line of the calculation results is defined as a water edge because the water edge in aerial photo is similar with the water edge at initial state of the numerical simulation. The extraction of riffle and pool is processed as follows: 1) pool develops extend to the upper and lower boundary of deep section, 2) riffle is defined as the section where riffle feature, narrow channel or fast flow, occurs in upper stream of pool, 3) the area of riffle and pool is within the water edge and upper and lower boundary of them, 4) riffle is classified into 4 types following the classification criteria.

3.4 Calculation of scenario

Table 3 Calculation conditions for two dimensional bed evolution analysis

Boundary Conditions	
Bed Elevation	April, 2009 and November, 2013
Bed Material	Single pattern from 6 patterns shown in Figure 10 to all grids
Calculation Section	11 km section from 9 km to 20 km from confluence point
Flow Regime	7 patterns Shown in Figure 9
Grid Number	Cross Stream : 21 for channel, 5 for each bank / Streamwise : 550
Time Step	0.4 econds
Manning's Coefficient	n = 0.022
Turbulent Flow Model	Zero-Equation Turbulence Model
Bedload sediment transport	Ashida-Michiue formula

Table 4 Combination flow regime and grainsize distribution for scenarios

Scenario no.	Flow regime	Grainsize distribution	D_{50} [mm]	Bedload transportation [m^3/year]
Scenario1	CaseF1	CaseG1	5.45	29000
Scenario2	CaseF1	CaseG2	2.13	34000
Scenario3	CaseF1	CaseG3	0.56	38000
Scenario4	CaseF1	CaseG4	2.00	35000
Scenario5	CaseF2	CaseG4	2.00	55000
Scenario6	CaseF3	CaseG4	2.00	92000
Scenario7	CaseF4	CaseG3	0.56	69000
Scenario8	CaseF5	CaseG5	2.43	121000
Scenario9	CaseF6	CaseG6	0.51	111000
Scenario10	CaseF7	CaseG1	5.45	39000

To estimate the suitable amount of sediment load for creating sweet fish habitat, the relation between examined by calculating twelve scenarios different in the amount of sediment load. The amount of sediment transportation is adjusted changing flow regime and grainsize distribution of sediment because Nays2DH cannot change the amount of sediment load directly. The calculation conditions is set as shown in table 3. Conditions other than flow regime and bed material are the same as the condition of reproduction calculation. Estimation of the suitable amount of sediment load and using correlation between the amount of sediment load and the area of developed riffle after flood. Numerical simulation was conducted about scenarios shown in table 43. Twelve scenarios are calculated the river bed evolution calculation in total.

Table 3 is a list of combination of flow regime and grain size distribution. D_{50} is initial median diameter of sediment. Bedload transportation is converted amount of the total amount of sediment through the channel within the scenario, thus divided by 55 months of the time duration of the calculation. Each case of flow regime and grain size distribution is shown in Figure 9 and 10. Scenario 1 is the calculation condition of reproduction calculation. Imaginary flow regime patterns are determined considering higher peak flow rate with the same total flow volume, or planned high flow volume as a peak flow rate. Imaginary grainsize distribution is determined referring that of river bank, and extremely small grainsize distribution.

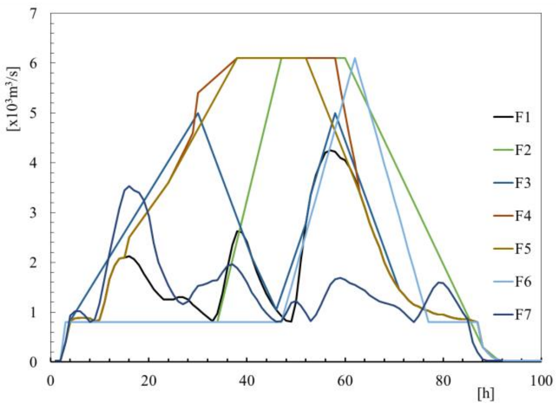

Figure 12 flow regime pattern

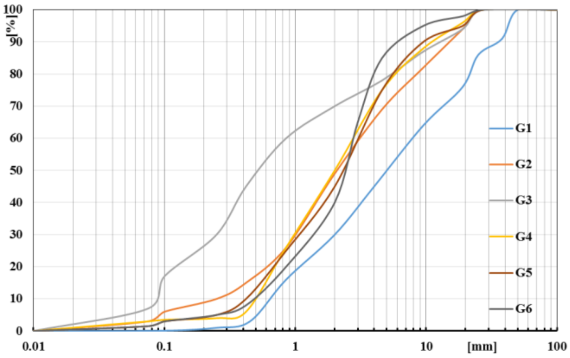

Figure 13 grainsize distribution patterns for the scenarios

4. Discussion

4.1 Estimation of suitable sediment

Figure 13 shows the relation between the sediment load and riffle area of each type, converge and traverse. Both converge type traverse type show the different quadratic approximation curve in center axis. Converge type is maximized at smaller sediment load than traverse riffle.

Other scenarios are classified into two groups by the amount of sediment load compared with scenario 7. In the group which sediment load is less than scenario 7, the size of a traverse riffle smaller than that of scenario 7. Figure 14 shows these two traverse riffle are different in width, though they develop in front of the same sand bar. Width of the riffle in scenario 7 is 136 m, but that in scenario 4 is 95 m of width. This can be thought as the difference in the amount of sediment deposited at traverse riffle. On the other hand, the group which sediment load more than scenario 7 does not have big difference in traverse riffle. Instead of that, their number of converge riffles tend to decrease. Compared with mean number of converge riffles of former group is about 2.7, of latter group is about 1.3. Flow regime of large amount of sediment group has high peak flow, therefore, it can be thought that large bed material which remains there in normal flood event are even moved in those scenario.

- Here, evaluation of each reproduction and growth habitat is considered. The correlation between sediment load and the suitability as growth habitat considering the difference among riffle types in suitability for growth habitat as shown in Table 1 is shown as orange line in Figure 15. Suitability as growth habitat is the product of a weighting for the riffle type and the area of the type, where weighting is equivalent to the number of sweet fishes in a square meters of the type of riffle. It is maximized at 52000 m^3/year. Evaluation of reproduction habitat is considered as the number of sweet fishes participating the reproduction action at the riffle. It is the product of the traverse riffle area, the capacity of ideal spawning redd, the proportion of ideal spawning redd to whole spawning redd, hatchability of them, and participation ratio in spawning, divided by spawned eggs by a female sweet fish and a pair. Capacity of ideal spawning redd is set as 100 million eggs per 100 m^2 [(26)]. The proportion of ideal spawning redd to the whole is 70%[27)]. Hatchability is 85%[28)]. Participation ratio in spawning is 85%[29)]. Spawned eggs by a female sweet fish is assumed as 4.5 $\times 10^4$ eggs per a individual[28)]. Sex ratio is assumed as one to one. It was maximized at 92000 m^3/year as shown as blue line in Figure 15. Then the sum of those approximation line, named as integrated evaluation, shown as green line in Figure 15 is maximized at 81000 m^3/year. Therefore, the suitable sediment load for sweet fish habitat is estimated about 53000 m^3/year for growth habitat, about 92000 m^3/year for reproduction habitat, about 81000 m^3/year for integrated habitat.

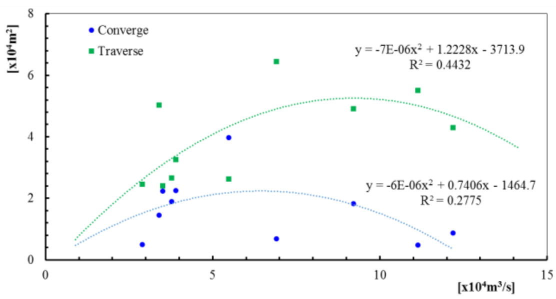

Figure 14 traverse and converge riffle area versus the amount of sediment load

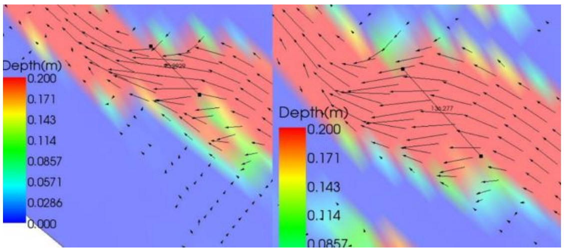

Figure 15 the difference of traverse riffle in width caused by the different amount of sediment load

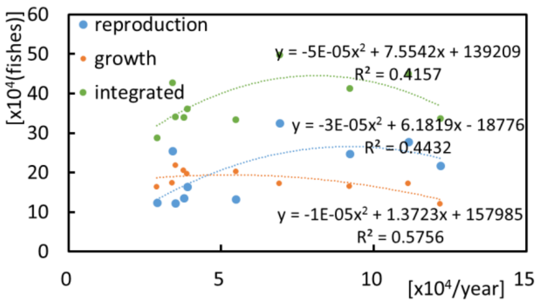

Figure 16 relation of sediment load and habitat potential for sweet fish

4.2 Environmental evaluation of sediment flow volume

Previous environment evaluation is based on past situation. The suitable river management condition havs been estimated from the historical comparison in a river focusing on various geomorphological parameter previously. The suitable sediment load in Kizu River have been estimated as the that in the past situation when the bed morphology is the most suitable for a certain evaluation object during the term investigated historical change. In this study, the suitable sediment load can be estimated directly evaluating bed morphology in the case that a certain amount of sediment is moved by numerical simulation.

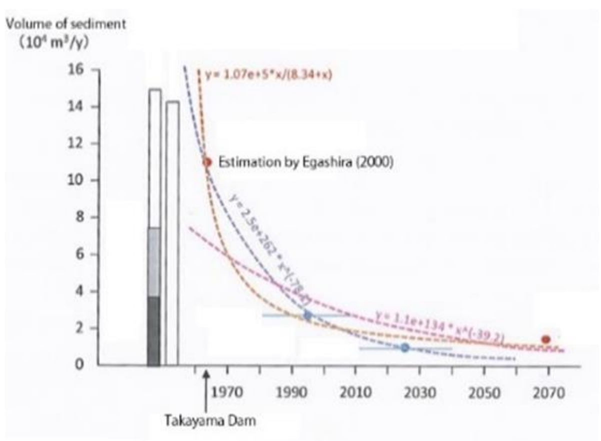

Figure 17 Damping curve for sediment volume

estimation by historical change analysis

5. Conclusion

In this study, the environmental evaluation of river bed geomorphology is achieved using the suitability of sweet fish as a criterion. Historical change showed the restoration of suitability as a reproduction habitat. However, converge riffle abundance oppositely changed compared with traverse type. As a hypothesis, the abundance of those type riffle is reciprocate.

The field survey is conducted to confirm the correspondence between riffle and reproduction habitat. Distribution of birds in autumn is obviously prejudiced by some geomorphological characteristics. There is loose positive correlation between the distribution of birds in reproduction season and the aspect ratio of riffle. It validated that traverse riffle is utilized as a reproduction habitat.

From the numerical simulation result of 10 scenarios, sediment load showed the correlation to each of the total area of converge and traverse riffle and the total area integrating growth and reproduction habitat. To estimate the suitable amount of sediment transportation for sweet fish habitat from the correlation between the sediment load and development river bed geomorphology, numerical simulation was conducted. The suitable sediment load was estimated as, about 53000 m^3/year for growth habitat, about 92000 m^3/year for reproduction habitat, about 81000 m^3/year for integrated habitat, which is as much as that in 1970s

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