HISTORICAL AND PHYSICAL EVALUATION OF FLOODPLAIN HABITATS IN THE RIVER CHANNEL OF THE KIKUCHI RIVER

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In Japan, with floodplain-dependent species being depleted by recent national land development and river improvement, the conservation of floodplains is recognized as a problem that must be urgently addressed. Therefore, floodplain ponds in the river channels that function as habitats for such species have been constructed. In the Kikuchi River, located in Northern Kumamoto Prefecture, the reduction of temporary waterbodies, such as floodplain ponds and floodplain-dependent species, has been indicated. In this study, to examine means of repairing these floodplain ponds, we quantitatively evaluate the current state of floodplain ponds, dead water regions, and low-velocity areas that can become habitats for floodplain-dependent species in the river channel. As a result, we evaluated each change in the distribution of floodplain ponds, transverse shape, river width/depth ratio, and the areas of the dead water and low-velocity regions using aerial photography (1947, 1959, 2009) and cross-sectional surveying results (1963, 2012).

1 INTRODUCTION

The Kikuchi River is inhabited by six types of Bitterling subfamily *Acheilognathinae* (an endangered species), as well as other floodplain-dependent species such as weather Loach *Misgurus anguillicaudatus* and Chinese false gudgeon *Abbottina rivularis* [1, 2]. These species are decreasing in number [2]. Therefore, measures must be taken to preserve the floodplain-dependent species. To take these measures, knowledge about the Kikuchi River, such as the present conditions of floodplain ponds and river channels and changes in the floodplain-dependent species habitat, needs to be accumulated. The reduction of floodplain ponds has been quantitatively clarified in the Kikuchi River. In particular, the secondary channel was almost disappeared and floodplain ponds on the sandbar were reduced about 60% [3].In general, the reduction factors of floodplain ponds include bed variation owing to gravel extraction, drying of floodplain ponds because of the reduction of the water level in the main stream by flow equalization from river prevention and water utilization projects, and the decrease of flood frequency by its division into two opposed channels [4, 5]. However, it has not been confirmed whether the same factors also affect the Kikuchi River. In addition, it has not been confirmed that altered floodplain ponds can be used by floodplain-dependent species or that the increase of dead water regions and low-velocity areas of the river channel could have a negative impact on such species.

The purpose of this study was to obtain the knowledge necessary to conserve the floodplain-dependent species of the Kikuchi River. The study quantitatively examined how changes in floodplain ponds can offer habitats to floodplain-dependent species and changes in the dead water regions and low-velocity areas of the river channel. In addition, we quantitatively evaluated changes in the river course channel morphology, which are believed to be a factor in the decrease of floodplain ponds.

2 MATERIALS AND METHODS

2.1 Study area

The Kikuchi River is located in the northern part of Kumamoto Prefecture, Kyusyu Island, Japan. The source is Fukaba (elevation 1,041m), Aso city, Kumamoto prefecture (Figure 1) [6].

The study was conducted at segment 2-2 (7–14 km from the estuary) and segment 2-1 (14–38 km from the estuary) of the Kikuchi River. These sections were considered because they are inhabited by many floodplain-dependent species, for example, Bitterling subfamily, Japanese rice fish *Oryzias latipes* and Chinese false gudgeon [7, 8].

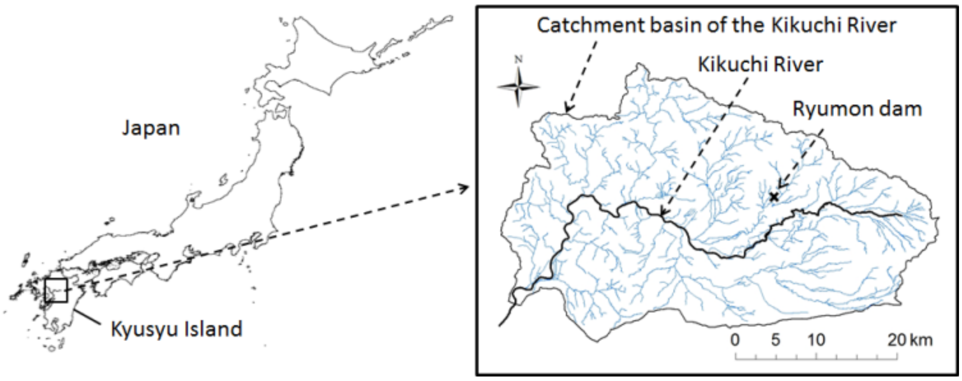


Figure 1. Study area

2.2 Evaluation of the current state of floodplain-dependent species habitat and river course channel morphology

We examined changes in floodplain ponds, floodplain-dependent species habitats, dead water regions and low-velocity areas of the river channel. In addition, we examined the changes of the river course channel morphology, which are considered to be a factor of decrease for floodplain ponds.

We used data from cross-sectional surveys between 1963 and 2012 (regular cross-sectional surveying in the Kikuchi River, Ministry of Land, Infrastructure, Transport and Tourism, Kyusyu Regional Bureau, Kikuchi River office), and six periods of aerial photography between 1947–2009.

We used the river simulation software iRIC (ver.2.2 [9]) for the hydraulic calculation (Table 1, Ministry of Land, Infrastructure, Transport and Tourism, Kyusyu Regional Bureau, Kikuchi River office).

Table 1. Specifications of aerial photos

Shooting date	Reduced scale	Shooting range (Distance from the river mouth)	Flow rate	Typology use	Area measurement
March-April 1947	1/30698	0k～55	unknown	●	
September 4th,1959	1/15000	7～23k、18～34k	unknown	●	●
August 7th,1971	1/5000	0～29.5k、29.5～50k	196.65m^3/s		
December 7th,1984	1/12500	0～22k、22～55k	14.30m^3/s		
March 6th,1996	1/25000	0～60k	9.30m^3/s		
May 2009	1/7500	0～52k	monthly average 12.85m^3/s	●	●

2.2.1 Change in the floodplain ponds

To evaluate the current state of floodplain ponds in the Kikuchi River, Minagawa et al. [3]examined floodplain ponds in three periods of aerial photos (taken in 1947, 1959, and 2009), as shown Table 2 [10]. It was divided into nine types at the place where the floodplain ponds appeared, connecting to the main channel (normal stage of water), flow water or stagnant water, and the direction of the opening. A fixed sandbar was used to judge whether the elevation difference between the sandbar and the low-water channel was higher than 3 m and if the area of vegetation was greater than 80% of the sandbar area using cross sections and aerial photos.

It is estimated whether floodplain ponds operated as floodplain-dependent species habitats according to the area, depth of the floodplain ponds and presence or absence of underflow water into the ponds [3, 11, 12].

Toward this goal, we examined the areas of the ponds, which could be read from aerial photos. By means of a survey of the ponds of the Kikuchi River, Minagawa et al. [3] had already revealed the changes in the total area of ponds per 1 km in the Kikuchi River, and that there is a positive correlation between the areas of ponds and the number of floodplain-dependent species in the ponds. However, they did not investigate the areas of the individual ponds and whether they functioned as floodplain-dependent species habitats. Thus, we found the changes in the floodplain ponds that act as habitats for floodplain-dependent species. The consideration was used the same data of floodplain ponds used by Minagawa et al. [3]. In addition, Minagawa et al. [3] found that the number of the floodplain dependent species was 0-1 species in ponds of are 200 m^2 or less and approximately 4 species in ponds of area 400 m^2 (Figure 2). Therefore, in this study, floodplain ponds with areas less than 200 m^2 were judged to have low-functionality as floodplain-dependent species habitats.

Table 2. Classification table of the types of waterbodies [3, 10]

Type	Appearing place	Connecting to the main channel (normal stage of water)	Flow	The direction of the opening
Downward-sandbar waterbocies	Sandbar	Connection	Stop	Downstream
Mid-sandbar waterbodies				Oposite bank
Upward-sandbar waterbodies				Upstream
Secondary channel on the sandbar			Flow	
Floodponds on the sandbar		Isolation	Stop	
Waterbadies on the fixed sandbar	Fixed sandbar	Connection	Stop	
Secondary channel on the fixed sandbar			Flow	
Floodponds on the fixed sandbar		Isolation	Stop	

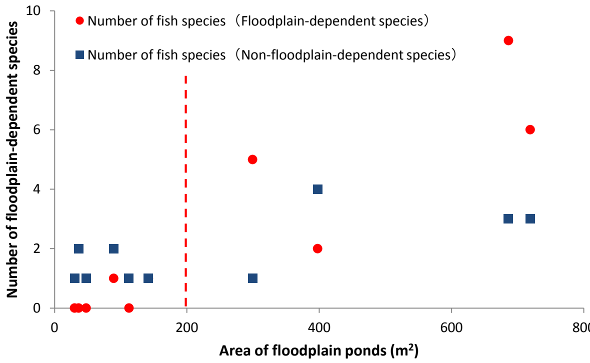


Figure 2. Relationship between the number of fish species and the area of floodplain ponds [3]

2.2.2 Change in the hydraulic parameters

To grasp the changes of the dead water region and low-velocity area of the river channel, we carried out a hydraulic calculation using the normal discharge (21.5 m^3/s) from 1963 to 2012 with a cross-sectional survey of the study area and the coordinates of the cross section. The areas of the dead water and low-velocity regions were calculated using the calculation results of the velocity by incorporation in GIS (ArcGIS 9). The changes were examined by comparing the areas of two time periods. Dead water was areas (define as areas with certain water depth with no flow) were estimated using the results of the hydraulic calculation. Low-velocity areas were defined as one in which 0 m/s < v $\leqq 0.1$ m/s [3]. Low-velocity areas could possibly be the habitats of Bitterling subfamily which was designated as endangered species and whose numbers have decreased in the Kikuchi River [3].

2.2.3 Change in the channel morphology

In addition to the above hydraulic calculation, the same were carried out using the average annual maximum flow (1,422.5 m^3/s) to assess the decrease in floodplain ponds. The B/h (river width/depth ratio) and dimensionless tractive force considered to be involved in the reduction of floodplain ponds was calculated for the 200-m pitch. The calculation used the hydraulic calculation results for the velocity and depth obtained cross-sectional surveys and particle size of the bed material (riverbed material research services in the Kikuchi River, Ministry of Land, Infrastructure, Transport and Tourism, Kyusyu Regional Bureau, Kikuchi River office). The riverbed material is configured of gravel and sand by about 50% respectively in the subject of the section. Moreover, its configuration was not a large change in 1978 to 2002[6].

B/h and dimensionless tractive force were used to calculate the average area flooded under an average annual maximum flow rate. B/h is said to show the sandbar form as Table 3, this study examined the changes of this form [14]. The coefficient of variation of B/h was also calculated to examine the dispersion of the river form. Dimensionless tractive force was calculated using the following formula [14]:

$$\tau_* = \frac{\mathrm{HI}}{\mathrm{sd}} \tag{1}$$

Table 3. B/h and sandbar form [14]

Depth ratio	Sandbar form
B/h＜30	Incomplete alternative bars and sandbars are hard to be formed.
30≦B/h≦70	Alternative bars are easy to be formed.
70≦B/h≦140	Alternative bars or double-row bars are easy tobe formed. (B/h≦100: Appearance limit of alternative bars.)
140≦B/h	Multi-row bars are easy to be formed.

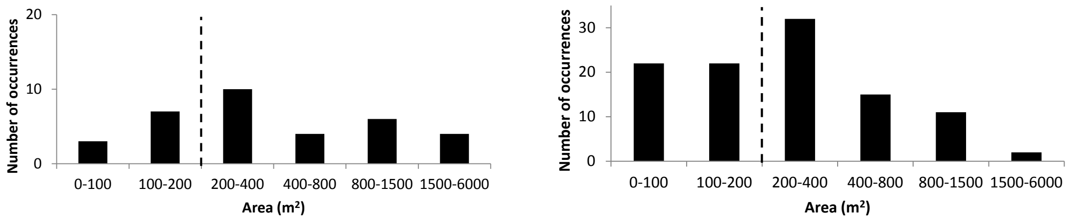
where H is the average annual maximum flow rate, I is energy grade during the average annual maximum flow rate, s is water specific gravity of the riverbed material (in this case, s=1.65), and d is representative grain-diameter.

Moreover, we compared the stream profile of the deepest riverbed values for two periods (1963, 2012), and we examined the relationship with the decrease factor of the floodplain ponds. The stream profile was drawn using data from the cross-sectional surveying of the study area.

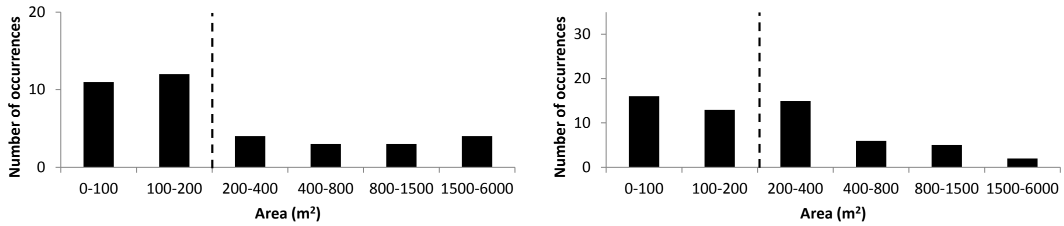
3 RESULTS

3.1 Change in the floodplain ponds

The floodplain ponds with areas of 200 m^2 or more were reduced by approximately 53% in the segment 2-1 and by approximately 42% in the segment 2-2 between 1959 and 2009 (Figure 3).



(a) 1959 Left: Segment 2-2, Right : Segment 2-1



(b) 2009 Left: Segment 2-2, Right : Segment 2-1

Figure 3. Number of occurrences of the floodplain ponds of each area

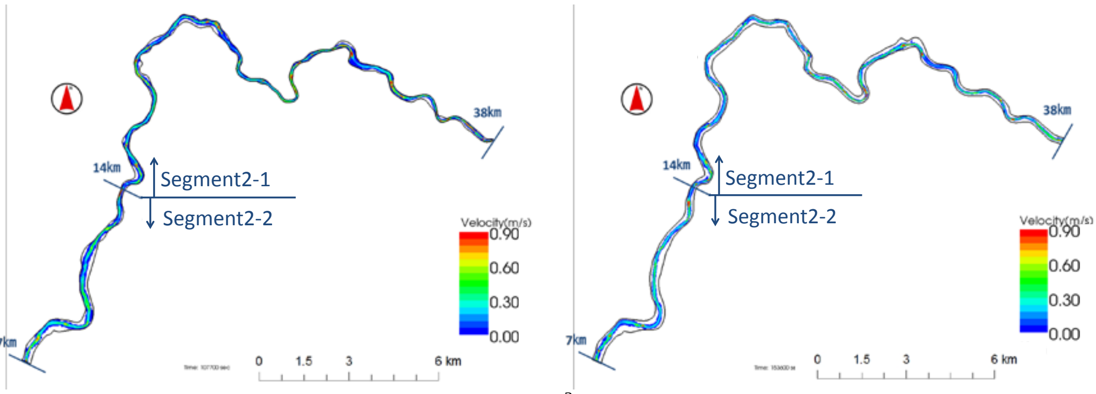
3.2 Change in the hydraulic parameters

The area of the river channel that was covered with water was reduced in 2012 from its value in1963 at the normal flow rate (Figure 4). Moreover, while the area in which the water flowed comprised the entire river channel in 1963, by 2012, there were areas in which the water did not flow in the average annual maximum flow rate.

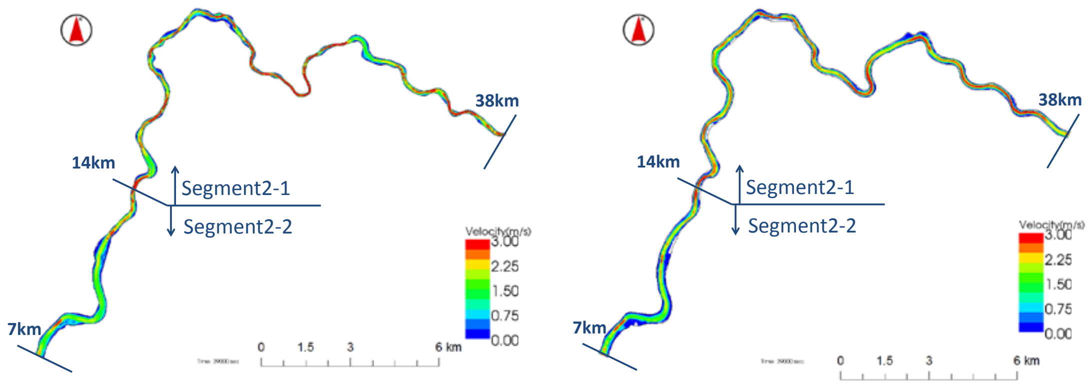
The dead water region was reduced to approximately 80%, and the low-velocity area was reduced by approximately 20% in segment 2-1 (Figure 5). Thus, the dead water region was reduced by approximately 35% and the low-flow area was almost constant.

3.3 Change in the channel morphology

The sandbar form was changed to the region of the alternative bars is easy to be formed to the region of the alternative bars or double-row bar is easy to be formed due to that B/h changed from 109.0 to 43.2 by average in the section of 7–14km (Figure 6). Although sandbar form (alternative bars can be formed easily) was the same, the average value of B/h decreases from 51.2 to 36.0 and from 45.0 to 40.2 on average in the sections of 14–25 km and 30–35 km, respectively. However, the region changed from incomplete alternative bars and sandbar is hard to be formed to alternative bars is easy to be formed due to that B/h changed from 14.0 to 34.0 in the section of 25– 30km. The coefficient of variation of B/h decreased by approximately 0.2 on average in the



(a) The normal discharge (21.5m^3/s) Left：1963, Right：2012



(b) The average annual maximum flow rate (1422.5 m^3/s) Left：1963, Right：2012

Figure 4. The flow velocity distribution chart

sections of 7–14 km, from 14–25 km, and 25–30 km; it decreased by approximately 0.1 on average in the section of 30–35 km (Figure 7).

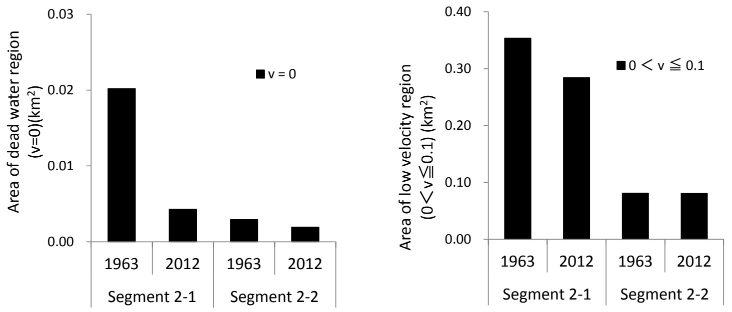


Figure 5. The histogram of area Left: dead water region Right: low-velocity area

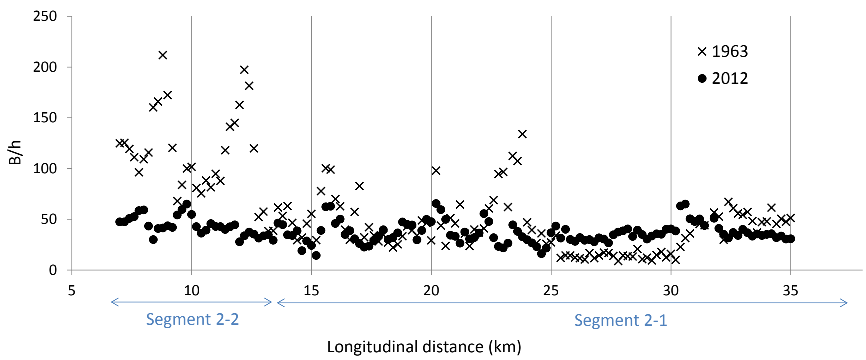


Figure 6. B/h (1963, 2012)

The dimensionless tractive force increased by approximately 0.1 on average in the sections of 7–14 km and 14–25 km (Figure 8). It also increased by approximately 1.4 on average in the section of 30–35 km. However, it slightly decreased by approximately 0.02 on average in the section of 25–30 km.

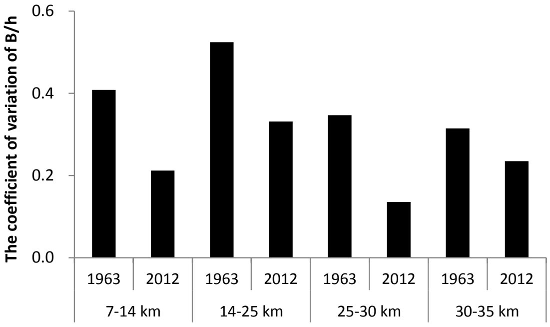


Figure 7. The change in the coefficient of variation of B/h

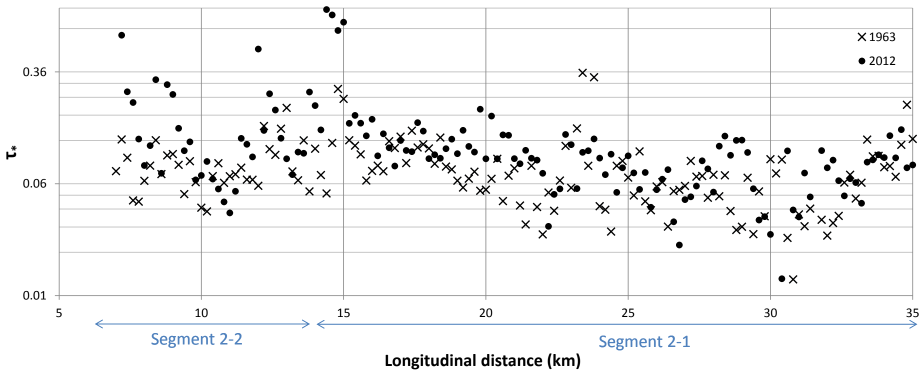


Figure 8. Dimensionless tractive force (1963, 2012)

The stream profile of the greatest riverbed depth (Figure 9) decreased on average by approximately 2.6 m in the section of 7–14 km, by approximately 1.9 m in the section of 14–25 km, and by approximately 1.5 m in the section of 30–35 km. While these sections decreased by approximately 2.0 m, the stream profile of the greatest riverbed depth decreased only by approximately 0.8 m in the section of 25–30 km.

These results are shown as Table 4 for each section. Items include the changes in the river course channel morphology and the reduction factors of floodplain ponds in each section. The change in the bed variation and the division into two opposite channels caused the decline of the river bed in the sections of 7 to 14 km (segment 2-2), 14 to 2 5km (segment 2-1), and 30 to 35 km (segment2-1).

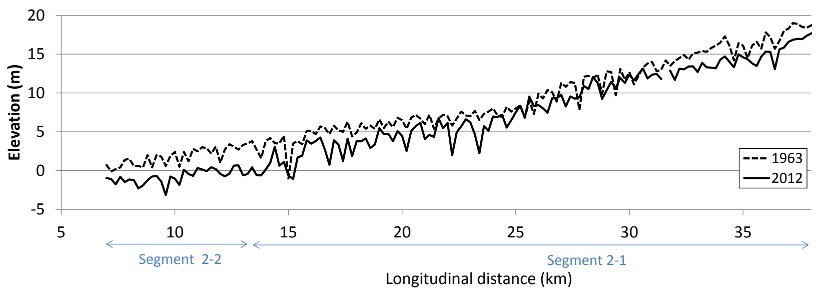


Figure 9. Stream-profile (1963, 2012)

Table 4. Changes in the river course channel morphology and the factors of each section

Section		Changes of the river course channel morphology				Factors affecting the decrease of floodplain ponds
Segment	Distance from the estuary	B/h	Coefficient of variation of B/h	Dimensionless tractive force	Deepest riverbed height	
2-2	7–14 km	Considerable decrease	Decrease	Increase	Considerable decrease	Sediment-trapping by Shiraishi slice (14.4 km) The division into two opposites of channel shape
2-1	14–25 km	Decrease	Decrease	Increase	Decrease	Division into two opposite channels Improvements such as widening of the river
	25–30 km	Increase	Slight decrease	Decrease	Slight decrease	Improvements such as widening of the river (water route)
	30–35 km	Decrease	Decrease	Increase	Decrease	Division into two opposite channels The river improvement such as widening of the river

4 DISCUSSION

It has been quantitatively clarified that the floodplain ponds with areas of 200 m^2 or more, the dead water region and the low-velocity area were reduced. These results suggest that the reduction of floodplain ponds serving as habitats for floodplain-dependent species had a negative effect on the numbers of such species.

This study examined only the areas of water bodies that could be read from aerial photos. In the future, since the connection frequency and flood frequency of water bodies is believed to affect the habitat of the floodplain-dependent species [15-17], we plan to consider changes in the connection frequency of water bodies and flood frequency of the Kikuchi River.

The reduction of the average of B/h was suggested that floodplain ponds decreased on the sandbar owing to the reduction of the sandbar itself by its change in form. The decrease of B/h was said to be caused by gravel-digging and the effects of dams [4, 5]. In the Kikuchi River, gravel-digging had been carried out from 1963 to 1981, peaking in 1971 to 1975, [18]. In addition, the Ryumon dam started construction in 1971 and was completed in 2002 in the Hazama River, which is connected to the main river 40 km from the estuary [19]. The river bed height significantly declined between 1963 and 1981 and has been stable since 1982 in the Kikuchi River [18]. Therefore, the cause of decline of river bed height was considered to be the gravel-extraction

The reduction of the coefficient of variation of B/h indicated that the diversity of river channel declined over the whole area. The cause of this change is believed to be that the monotonous channel shape owing to river improvements such as embankment, the digging of riverside, and the equipment of revetments [4]. These improvements were conducted from 1940 in the wake of the floods of 1928 and 1935.

The dimensionless tractive force increased in the B/h declined section. In particular, it is believed that the dimensionless tractive force increased in the area of flooding owing to its division into two opposite channels. The reason for this phenomenon was considered to be the decline of the riverbed. The division into two opposites was considered to have caused a decline in the flood frequency of sandbars and the overgrowth of vegetation.

According to the changes in the river course channel morphology, the decrease sandbars and flood frequency were considered to be the main cause of the decrease of floodplain ponds. In particular, the division into two opposite channels caused the decline in flood frequency and overgrowth on the sandbar [11]. However, river improvements were considered the main factor because these sections were being equipped with revetments and subject to river-widening. Thus, B/h increased in the section of 25 to 30 km. However, floodplain ponds disappeared at the time of the widening of the river. As above, the reduction factors of the floodplain ponds were overgrowth and the decline of flood frequency; this also happened with the Kizu and Yodo Rivers [20-22]. On the other hand, the excavation of sandbars by river improvement was considered as one factor in the decrease of floodplain ponds in the Kikuchi River.

This study calculated the dimensionless tractive force as an average for each cross section. However, it was believed that dimensionless tractive forces differed by location such as the low-water channel and sandbar in the river channel. Therefore, the force has a different effect, such as the degradation of riverbed and disturb on the sandbars, for each location [4, 23]. Therefore, in the future, we plan to consider the dimensionless tractive force in each place and the relationship between overgrowth, division into two opposite channels, and the force.

5 CONCLUSION

This study investigated to obtain the knowledge to examine conservation techniques of the floodplain dependent species in the Kikuchi River. The result is as follows. It was suggested that it have a negative impact on the habitat of the floodplain dependent species by decrease floodplain and dead water regions and low velocity legions of the river channel with an environment that can live dependent species. Also, the River course characteristics became clear that changes quantitatively, and it was considered to be a factor to the reduction of the floodplain ponds. The factor of the change in the river course channel morphology amount was considered to gravel extraction.

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