**Research Paper (revised)**

# Study on segment-based ecoregions using fish fauna for conserving river environments in Kyushu, Japan

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## Abstract

Selecting suitable river revitalization project sites or performing ex-post evaluation requires ecoregions where the biological integrity is comparable. Whereas, to evaluate the integrity of a river ecosystem that varies from the headwater to downstream regions, an adjustment of the ecoregion according to the longitudinal change of biota is necessary. We defined the regions where biota are identical according to the direction of change along the stream path as “segment-based ecoregions.” We delineated segment-based ecoregions using fish fauna data for three Ecoregions (the northwest Kyushu, the northeast Kyushu, and the south Kyushu) in Japan, and extracted indicator fish species of each segment-based ecoregions. Therefore, the northwest Kyushu Ecoregion was divided into five, the northeast Kyushu Ecoregion into three, and the south Kyushu Ecoregion into five segment-based ecoregions. Classifying fish fauna in the same ecoregion enables classification by difference of longitudinal change of stream path in preference to difference of watersheds. In addition, particular topographic regions such as large low-lying floodplain area of the northwest Kyushu Ecoregion and amphitheater areas of the south Kyushu Ecoregion were classified to be independent segment-based ecoregions. Indicator fish species of segment-based ecoregions reflected the fish fauna of each ecoregions in the midstream area, such as *Acheilognathinae* of the northwest Kyushu Ecoregion and migratory *Gobiidae* of the south Kyushu Ecoregion. Applying the segment-based ecoregion concept to enable a comparison of the biological integrity of fish fauna depends on a common environmental type between watersheds.

**Keywords:** segment-based ecoregion, longitudinal gradient, fish fauna, ecoregion, river environment management

## 1. Introduction

River revitalization and environmental conservation projects have been practiced worldwide (Clarke et al. 2003, Shields et al. 2003). Environmental indicators that can evaluate biological integrity are necessary to select suitable project sites or perform ex-post evaluation. Various different indicators have been independently developed. River Invertebrate Prediction and Classification System (RIVPACS) and Index of Biological Integrity (IBI) are examples of representative indicators. RIVPACS measures the degree of human impact to aquatic environments by comparing the observed biota with predicted biota on the basis of the biological prediction model developed from the physical and chemical features of multiple sites (Wright, 2000). The biological integrity of study sites is evaluated by the IBI by comparing the calculated value of the index represented by the sum of multiple exponentials under reference conditions (Karr 1981 1991). Within both aforementioned methods, it is necessary to decide on an appropriate reference condition.

These indicators are effective within geographical regions where the biological integrity is comparable. This geographical region is termed an “ecoregion.” Research into defining ecoregions or the selection of reference conditions have been predominantly conducted in Europe and the United States. Bailey (1976) has defined an ecoregion as a geographical region of fairly homogeneous soil type, climate condition, and vegetation. Hall et al. (2000) reported that biological integrity comparisons should be conducted among common ecoregion types. Omernik (1987) has used the ecoregion concept and argued that the reference condition should be identified within an ecoregion. The ecoregion concept has been widely adopted in North America to develop biological indicators (Crowley, 1967; Bailey & Cushwa, 1981). On a global scale, the world’s terrestrial ecosystems were classified into 867 ecoregions on the basis of classical biogeography by Olson et al. (2001). The ecoregion concept is particularly effective in countries belonging to the Asian monsoon region, because these countries contain complex topographies (i.e., several peninsulas and islands) and fauna that is very finely delineated based on climate. Cannon et al. (2007) have generated a comprehensive and detailed map of forest ecoregions to identify conservation priorities on the island of Sulawesi, Indonesia. However, limited attempts have been made to implement the ecoregion concept, particularly within freshwater communities. Itsukushima (2011) has delineated ecoregions using the data of fish fauna of the Kyushu Island, Japan, and reported the effectiveness of the method for deciding conservation strategies.

Vannote et al. (1980) have revealed that the stream ecosystem varies from the headwaters to downstream regions along with the gradient of increasing channel dimensions and an opening of the riparian canopy (River Continuum Concept). The studies that can be cited for detailing the longitudinal direction change of biota are mentioned below. Ivkovic (2014) has studied blackfly species compositional structure and distribution along a longitudinal gradient of water temperature, alkalinity, conductivity, and habitat type in the Plitvice Lakes area of Croatia. Bond (2015) has examined the spatial distribution of river fishes, benthic invertebrates, and organic matter along lateral and longitudinal gradients in two hydropeaking and eight natural Lake Superior tributaries in Ontario, Canada. In a previous study, we have investigated the relationship between longitudinal changes of fish fauna and Yamamoto's segment classification (Yamamoto, 2004) defined from the perspective of flood control (Itsukushima, 2008). The determination of indicator fish species for each segment of the stream path is effective to plan a conservation strategy (Bram and Piet, 2003).

Whereas, there are many researches which classify the channel characteristic by channel morphology or structure. Planform of river channel (meandering, braiding or anabranching) was often used for classifying channel morphology (Melton, 1936; Leopold and Wolman, 1957; Schumm, 1985). Rosgen (1994) proposed seven major stream type categories that differ in entrenchment, gradient, width/depth ratio, and sinuosity. The relation between channel geometry and flow regime was investigated in a number of geographical region, because channel morphology differs in geology or climate. Several regional equations that yields bankfull channel width using drainage area were proposed (Chaplin, 2005; Cinotto, 2003; Keaton et al., 2005; McCandless, 2003a; McCandless, 2003 b; MetCalf, 2004; Miller and Davis, 2003; Sweet and Geratz, 2003; Westergard et al., 2004; Mohamoud et al., 2006). Splinter et al., (2010) compared relation between drainage area and channel characteristics among three ecoregions. Yamamoto (2004) classified river channel geometry along longitudinal direction for Japanese large river. He proposed the following four segments; mountainous channel (channel slope > 1/60), alluvial fun channel (channel slope: 1/60～1/400), natural levee channel (1/400～1/5,000) and delta channel (channel slope < 1/5,000). Longitudinal change of river channel geometry exerts influence on river ecosystem. Huet (1959) divided four biological zones correspond to slope of stream bed by investigating fish fauna in Western Europe.

However, the aforementioned studies on the longitudinal changes of biota are generally intended for individual watersheds. To evaluate the integrity of a river ecosystem that varies from the headwater to downstream regions, an adjustment of the ecoregion according to the longitudinal change of biota is necessary. In our previous research, we defined the regions where biota are identical according to the direction of change along the stream path as “segment-based ecoregions,” and proved these units effective for evaluating river environments (Itsukushima 2011).

In the current study, we investigated the pattern of longitudinal fish distribution within the Kyushu region for establishing segment-based ecoregions. In addition, we discussed the relationship between physiographic factors and the results of classification, and identify the indicator fish species of each segment-based ecoregion.

## 2. Methods

### 2.1. Study area

The current study focused on 8 rivers of Kyushu Island, Japan. In our previous study (Itsukushima, 2011), out of the 21 rivers analyzed, 19 rivers were classified into four ecoregions: northwest Kyushu Ecoregion (10 rivers), northeast Kyushu Ecoregion (three rivers), south Kyushu Ecoregion (eight rivers), and Amami-Oshima Ecoregion (one river). The current study focused on two ecoregions (northeast Kyushu Ecoregion and south Kyushu Ecoregion) that belong to the Kyushu main Island. The length of the main river channel and watershed area of each river is listed in Table 1.

### 2.2. Fish fauna data

We used presence–absence fish fauna data investigated by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT; The National Census on River Environments from 1992 to 2010) in 8 rivers and at 99 points (Fig. 1). We used data for brackish and saltwater fishes, migratory fishes, and freshwater fishes. Data for invasive alien species and alien species were omitted because these species did not reflect potential fish fauna of the target region. If the species was captured during at least one survey between 1992 and 2010, we regarded a fish species to be an inhabitant of the investigation point.

## 2.3. Topography data

Gradient of channel slope (G), altitude (AL), distance from river mouth (D) were used as topographic factor. These values were obtained from electronic map of Geospatial Information Authority of Japan and published data of MLIT. Gradient of channel slope (G) was calculated by Log (1/S) [S: bed slope]. In addition, sinuosity (P), degree of braiding (B), degree of anabranching (A), and ratio of surface wide to river width (W/L) was adopted as indicator of river planform by reference to Schumm (1985). We measured these values using aerial photo by planimeter within one reach (10 times of the river wide). These indicators of river planform was measured with the exception of tidal reach.

## 2.4. Statistical analysis

The fish fauna data for each site were classified based on similarity by TWINSPAN (Two-Way Indicator Species Analysis, Hill 1979). PC-ORD ver. 4 (MjM Software Design) was used to calculate TWINSPAN. The pseudo-species cut-off levels were defined as 0 (i.e., presence-absence), and the maximum number of indicator species for a division was set at five.

In addition, IndVal (Indicator Species Analysis) (Freemark et al., 2002) was executed to determine indicator species of each groups divided by TWINSPAN. Index value ranges from 0 to 100 % and indicates degree of concentration in specific groups.

Further, decision tree model was executed to identify a topographic factor that contributes to classifying segment-based ecoregions. The seven topographic and river planform factors (G, AL, D, P, B, A, W/L) were used as explanatory variable and the classification result of TWINSPAN used as objective variable. Gini index was adopted for judgment criteria and analysis was conducted by statistical software “R”.

Finally, PCA (principal component analysis) was executed to investigate river channel characteristic of each site using topographic and river planform factors. The difference of topographic and river planform factors was analyzed by one-way analysis of variance and honestly significant difference.

### 2.5. Fish fauna characteristics of each ecoregion

Table 2 indicates the average number of fish species (total number of species, *Cyprinidae*, *Acheilognathinae*, *Gobiidae,* and excluding *Cyprinidae* and *Gobiidae*) in each river belonging to the northwest Kyushu Ecoregion, northeast Kyushu Ecoregion, and south Kyushu Ecoregion. The ecoregions containing the highest number of fish species from the largest to smallest was the northwest, northeast, and south. In the northwest Kyushu Ecoregion, *Cyprinidae* species were most abundant; however, the *Gobiidae* species were the fewest of the three ecoregions. In the south Kyushu Ecoregion, *Cyprinidae* species were the fewest; however, the *Gobiidae* species were most abundant. The fish fauna of the northeast Kyushu Ecoregion were intermediate between those of the northwest Kyushu Ecoregion and the south Kyushu Ecoregion.

## 3. Results

### 3.1. Segment-based ecoregions of the northeast Kyushu Ecoregion

Figure 2 shows the classification result of TWINSPAN for 27 sites (three rivers). The indication method of the analysis result is detailed below. During the first step, the 27 sites were categorized into five sites belonging to the estuarine area (group A), whereas the remaining 22 sites were classified by the appearance of *Konosirus pumctatus*. During the second step, group A was further divided into groups A1 and A2 by the appearance of *Cyprinus carpio*, whereas the remaining 22 points were classified into six sites (group B) and 16 sites (group C) by the appearance of *Mugil cephalus*. During the third step, group B was classified into groups B1 and B2 by the appearance of *Acanthogobius lactipes,* and group C was classified into groups C1 and C2 by the appearance of *Pelteobagrus nudiceps*.

The classification results are shown in Figure 3 (group A–C). Figure 3 indicates the longitudinal classification from downstream to upstream from groups A to C. Further classification indicates that the estuarine area (group A) comprised the river mouth of the Yamakuni River and others. In addition, group C was classified into the sites belonging to the Yamakuni River and other sites where *Pelteobagrus nudiceps* was confirmed. To classify the three groups, investigation points were classified reflecting the longitudinal distribution of fish fauna. However, in the case of classifying six groups, investigation points were classified by the differences of the watershed such as the upper reaches of the Yamakuni River and the remaining two rivers. Therefore, classifying fish fauna using ecoregion classification enables the investigation points to be divided according to the longitudinal stream path before the differences in the watershed. As mentioned above, in the northeast Kyushu Ecoregion, it is appropriate to divide the region into three segment-based ecoregions as groups A (estuarine area), B (midstream area), and C (upstream area).

### 3.2. Segment-based ecoregions of the south Kyushu Ecoregion

Figure 4 shows the classification result of TWINSPAN for 72 sites (five rivers). During the first step, all 72 sites were classified into ten sites comprising the estuarine area (group A), whereas the remaining 62 sites were classified by the presence of *Takifugu niphobles*. During the second step, group A was further divided into groups A1 and A2 by the presence of *Zacco platypus*, and the remaining 62 points were classified into 23 sites (group B), whereas the remaining 39 sites were classified by the appearance of *Rhinogobius giurinus*. During the third step, group B was classified into groups B1 and

B2 by the appearance of *Tanakia lanceolata, Sicyopterus japonicus*, and *Silurus asotus*, whereas the remaining 39 sites were classified into group C, and the other 17 sites by the appearance of *Carassius auratus langsdorfii* and *Odontobutis obscura*. During the final step, group C were divided into groups C1 and C2 by the appearance of *Plecoglossus altivelis,* Pseudorasbora parva, and *Rhinogobius kurodai*, and the remaining 17 sites were classified into nine sites (group D) and eights sites (group E) by appearance of *Oncorhynchus masou*.

Classification results are shown in Figure 5 (groups A–E). In Figure 5, the fish fauna among the five rivers were classified longitudinally from downstream to upstream as groups A (estuarine area), B (downstream area), D (upstream area), and E (headwater area), except for group C. Group C was composed of the upstream area of the Oyodo and the Sendai rivers, and was located at a more upper reach than group D. Figure 6 indicates the contour of the geological gradient and classification result for fish fauna for the south Kyushu Ecoregion; the low gradient area is colored green and the steep area is colored red. The low gradient area approximately 60 km from the river mouth comprises the Kakuto and Okuchi amphitheaters (the Sendai River) and the Miyakonojo and Kobayashi amphitheater (the Oyodo River). Therefore, group C was composed of sites belonging to amphitheater areas, suggests that it has a different fish fauna from other groups.

The result of further classification of group A (estuarine area) resulted in the three sites belonging to the Sendai and Oyodo rivers (A1) and sites belonging to other streams (A2). Group B was composed of sites belonging to the Sendai River (B1) and sites belonging to other streams (B2). These classification results of A1, A2, B1, and B2 were due to difference of fish fauna of the watershed. When classifying the fish fauna into five groups, fish fauna were divided not only by the longitudinal distribution pattern, but in addition during the next step (eight groups), fish fauna were classified by the differences between the basins. Therefore, it is appropriate to classify the segment-based ecoregions of the south Kyushu Ecoregion into five groups: group A: estuarine area, group B: downstream area, group C: amphitheater area, group D: upstream area, and group E: headwater area.

### 3.3. Result of IndVal analysis

Table 3 indicates result of IndVal analysis in the Northeast Kyushu Ecoregion. Index value of freshwater fish was extremely low and diadromous *Gobiidae* such as *Tridentiger obscurus* and *Gymnogobius breunigii* were confirmed with high frequency in Group A. In Group B, index value of *Rhinogobius giurinus* and *Gymnogobius urotaenia* was particularly high. Index value of diadromous fishes were low in the Group C which located upper region. Whereas, index value of *Nipponocypris temminckii*, *Pungtungia herzi* or *Rhinogobius* such as *Rhinogobius flumineus* was high.

Table 4 indicates result of IndVal analysis in the South Kyushu Ecoregion. In tidal reach (group a), index value of seven species exceeded 30 %, except for *Anguilla japonica* the whole species were belonged to diadromous *Gobiidae*. The index value of *Plecoglossus altivelis* and *Hemibarbus labeo* in addition to diadromous *Gobiidae in* group B. In group C, few species indicates high index value, only *Odontobutis obscura* was exceeded 30 %. In group D, index value of *Rhinogobius fluviatilis* and *Rhinogobius sp.CO* which were rarely confirmed lower reach was high. In the most upper reach (group E), *Rhynchocypris oxycephalus jouyi* and *Oncorhynchus masou masou* which are cold-water fishes showed high value.

### 3.4. Topographic factor contribute to classifying segment-based ecoregions.

Figure 7 (a) shows the result of decision tree model for northeast Kyushu ecoregion.

Gradient of channel slope (G) was the most contributing factor to classify group B and group C. River bed slope of the sites belonged to group C was steeper than 1/514. Accuracy rate of this model was 94 %.

Figure 7 (b) shows the result of decision tree model for South Kyushu ecoregion. The sites belonged to group B were classified by AL (AL < 27.87 m, accuracy rate: 92%) at the first step. At the second step, the sites belonged to group E were classified by D (AL > 217.9 m, accuracy rate: 86%). At the final step, remaining sites were classified into group C (D ≧ 49.6 km, accuracy rate: 90 %) and group D (D < 49.6 km, accuracy rate: 55 %). Therefore, the result of fish fauna classification is thought to be corresponded to topographic factor (D, AL, and G).

### 3.5. Characteristics of topographic factor and indicator of river planform

The result of comparison for topographic factor and indicator of river planform among each groups in two ecoregions was indicated in Table 5 In the northeast Kyushu Ecoregion, significant difference was found in topographic factor (G and D), however was not found in indicator of river planform. In the south Kyushu Ecoregion, significant difference was found in all topographic factor was not found in indicator of river planform as is the case with the northeast Kyushu Ecoregion. The topographic factor was changed accompanied along the stream path in the northeast Kyushu Ecoregion. Whereas, group C of the South Kyushu Ecoregion containing sites belonged to amphitheater had characteristic of low gradient and large distance from river mouth.

Figure 8 indicates result of PCA to investigate relation of topographic factor and indicator of river planform in the northeast Kyushu Ecoregion. Contribution rate of the first main component was 45.1 % and correlation coefficient was high in order L/W (0.47), D (0.44), AL (0.37) and B (-0.46). Contribution rate of the second main component was

21.2 % and correlation coefficient was high in order S (0.67) and AL (-0.43). Therefore, the first main component indicates the change of stream path from upstream to downstream and the second main component indicates channel planform especially meandering. The value of the first main component of Group B was less than -1.1, and the value of the second main component was concentrated from 0 to -1.0 except for one site. Whereas, the value of the first main component and the second main component of group C varied widely.

Figure 9 indicates result of PCA to investigate relation of topographic factor and indicator of river planform in the South Kyushu Ecoregion. Contribution rate of the first main component was 33.7 % and correlation coefficient was high in order AL (0.57), D (0.53), and G (-0.49). Contribution rate of the second main component was 24.2 % and correlation coefficient was high in order B (0.71) and L/W (-0.62). Therefore, the first main component indicates the change of stream path from upstream to downstream as with the north east Kyushu, and the second main component indicates channel planform especially braiding. As for the first main component, barycenter of each group moved in a positive direction toward upper reach. Whereas, the value of the second main component of each group varied widely.

## 4. Discussion

### 4.1. Fish fauna characteristic of each segment-based ecoregion

In this section, we discuss the fish fauna characteristics and determine the indicator species each segment-based ecoregion of the northeast Kyushu Ecoregion. Average number of fish species (all species, freshwater fish species, and brackish and saltwater fishes) of each segment-based ecoregion is shown in Figure 10. A declining average number of all species was evident from downstream to upstream, in the order of group A

(25.2 ± 3.2), group B (16.7 ± 2.5), and group C (16.7 ± 2.9). The number of freshwater fish species was the largest in group B (13.7 ± 1.8) and the smallest in group A (7.0 ± 4.8). The number of freshwater fish species of group C (13.3 ± 2.9) was similar to group B. Brackish and salt water fishes were confirmed in groups A and B, but did not inhabit group C. The number of brackish and salt water fishes were considerably different between groups A (18.2 ± 5.0) and B (3.0 ± 1.3), although these two groups were both affected by the tide. The reason for the increase in the total number of species from upstream to downstream may be because of a widening of the river space in the downstream reaches, thereby increasing the utilizable habitat type and area for various species. This phenomenon was observed in the Monkey River, Belieze (Esselman, 2006). Therefore, it is necessary to consider these differences of fauna distribution during the planning of a conservation strategy or the implementation of nature restoration projects. Thus, the concepts of segment-based ecoregions were effective in the northeast Kyushu Ecoregion.

Next, we discuss the fish fauna characteristics and determine the indicator species of each segment-based ecoregion of the south Kyushu Ecoregion. Figure 10 shows the average number of fish species (all species, freshwater fish species, and brackish and saltwater fishes) of each segment-based ecoregion. The average number of all species and brackish and salt water fishes were largest in the most downstream segment-based ecoregion (group A) and declined in the upstream direction. Fresh water fish species were most abundant in group B and declined upstream and downstream. The average number of freshwater fish species of group C (9.6 ± 2.7) and group B (9.9 ± 0.9) were similar.

Further, we discuss the fish fauna characteristics of the amphitheater areas (group C). Topographic characteristics of these amphitheater areas were the high altitude and low gradient of the bed slope. It is thought that the fish fauna inhabiting this region are dependent on these topographic characteristics. Table 6 shows a comparison of the occurrence ratios of typical fish species between sites belonging to amphitheater areas (Miyakonojyo amphitheater: ten sites, Kobayashi amphitheater: three sites, Oguchi amphitheater: five sites, and Kakuto amphitheater: two sites) and the sites of the northwest Kyushu Ecoregion. Sites belonging to the northwest Kyushu Ecoregion were identified by classifying every altitude class (−10–0 m, 0–40 m, 40–100 m, and 100–200 m). Altitudes of sites belonging to the amphitheaters were similar at 100–200 m. The occurrence ratios of cold water fishes such as *Nipponocypris temminckii* and *Rhynchocypris oxycephalus jouyi* were high in the amphitheater areas, and this tendency occurred within the sites falling within the 100–200 m altitude of the northwest Kyushu Ecoregion. In addition, the occurrence ratios of *Cyprinus carpio*, *Carassius auratus langsdorfii*, and *Pseudorasbora parva* were high in the amphitheater areas. In the northwest Kyushu Ecoregion, the occurrence ratio of these fishes were similar to the sites falling within the altitude of −10–40 m, whereas these species were rarely confirmed at the sites falling within the altitude of 100– 200 m. In contrast, the occurrence ratio of anadromous *Gobiidae* that are a typical species of the south Kyushu Ecoregion, were low in the amphitheater area. Because the amphitheater region is situated away from the river mouth, it is considered that the migrations of these fish species were inhibited by a massive dam. As mentioned above, species composition of group C was distinguishable because it divided groups B and C as different segment-based ecoregions.

### 4.2. Indicator fish species of each segment-based ecoregion

Among freshwater organism, fish is sensitive to habitat change or environmental degradation and consider to be keystone communities (Karr 1985, Kwon 2012). Therefore, fishes are used as indicator species (Filgueria 2016). In addition, longitudinal change of fish fauna along stream path was recognized and indicator species decided with respect to longitudinal section in Europe (Huet 1959), North America (Matthews 2000), South America (Petry 2006), and Oceania (Hayer 2010). Additionally, research of environmental evaluation or investigating anthropogenic impact such as cross-drainage work was conducted based on longitudinal change of fish fauna (Lanse 2007, Vasek 2016). Whereas, indicator fish of longitudinal zonation was criticized for lacking consideration of regional ecosystem (Park et al 2006), therefore, concept of ecoregion should be introduced to deciding longitudinal indicator species. Fish species showing a high occurrence ratio in a particular segment-based ecoregion should be selected as the indicator species because these fishes depend on a distinctive environment of the segment-based ecoregion. The presence or absence of indicator species is not intended to directly represent the integrity of river environment, however, indicator species is available as target of river revitalization projects or conservation. From the abovementioned perspective, we identified indicator fish species of each segment-based ecoregion as follows:

The northeast Kyushu Ecoregion

- Group A: *Konosirus pumctatus*, *Gymnogobius breunigii*
- Group B: *Rhinogobius giurinus*, *Gymnogobius urotaenia*, *Tridentiger obscurus*
- Group C: *Pungtungia herzi*, *Rhinogobius flumineus*

The south Kyushu Ecoregion

- Group A: *Takifugu niphobles*, *Glossogobius olivaceus*, *Eleotris acanthopoma*
- Group B: *Gymnogobius urotaenia*
- Group C: particular fish fauna adopted to a combination of high altitude and low gradient
- Group D: *Rhinogobius fluviatilis*, *Rhinogobius sp. CO*

Group E: *Oncorhynchus masou masou*

In the northeast Kyushu Ecoregion, each segment-based ecoregion was characterized by the *Gobiidae* instead of *Cyprinidae,* unlike the indicator fish species of the segment-based ecoregions belonging to the northwest Kyushu Ecoregion (Itsukuhsima 2011). Similar to the indicator fish species of the segment-based ecoregions of the northeast Kyushu Ecoregion, each segment-based ecoregion was characterized by the *Gobiidae*. In addition, results of the classification and the unique environment of the amphitheater were extracted, and indicator species that reflect the fish fauna of southern Kyushu have been extracted.

### 4.3. Relation between topographic factor and channel planform

In this section, we discuss the relation between topographic factor and channel planform. Meandering is the important factor influencing habitat, because meandering characteristics dominate bar behavior or riffle and pool structure (Ferguson 1981). Many researchers investigated relation between meandering characteristics and river bed slope in mountainous rivers, alluvial rivers or tidal rivers. Dade (2002) found out decreasing sinuosity accompanied with increasing gradient by comparing bed-load river and mixed load river. Similar results were proposed by Rosgen (1994). He defined sinuosity of Aa+ channel type as 1.0～1.1, and sinuosity of E channel type as over 1.5. Whereas, opposite phenomena was observed in low gradient delta channel (gradient 1/4,000 ～ 1/50,000) in Okavango, Botswana (Tooth 2004). In addition, similar result was obtained in tidal river (Kleinhans 2009). These conflicting results presents difficulty of formulating relation between channel gradient and sinuosity (Kleinhaus 2011). Because, many factors such as vegetation (Tal 2001, Baker 1978), river bank materials (Schwendel 2015), and river bed materials (Hey 2006) influence sinuosity.

Figure 11 indicates the relation between channel gradient and sinuosity in the Northeast and South Kyushu Ecoregion. In the segment-based ecoregions composed of low gradient sites, sinuosity increases corresponding to decreasing channel gradient. Whereas, converse phenomenon was observed in the segment-based ecoregions composed of high gradient sites belong to South Kyushu Ecoregion. However, further information such as cross section profile or river bed materials are needed to formulate sinuosity.

### 4.4. Application for river environment management

Evaluating river environment based of reference condition in ecoregion is needed for selecting sites of river revitalization or environmental conservation. In the continental rivers where scale of geological unit is large, change of biota along stream path is moderate and its scale is comparable to ecoregion. In response, the rivers belong to peninsulas or islands, geological or climate unit is finely divided, change of biota along stream path is remarkable. Therefore, ecoregion based on longitudinal change of biota in single ecoregion is essential as the smallest unit for evaluating river environment. Further research of segment-based ecoregions such as verification using other taxonomic group or investigating river channel morphology is needed. However, the concept of “segment-based ecoregion” provides important perception for river environment management.

## 5. Conclusion

The objective of this study was to classify segment-based ecoregions using fish fauna for multiple watersheds in three Ecoregions. The acquired knowledge from the results is mentioned as follows:

1. By the results of analysis, the northwest Kyushu Ecoregion was divided into five, the northeast Kyushu Ecoregion into three, the northeast Kyushu Ecoregion into three, and the south Kyushu Ecoregion into five segment-based ecoregions. It was revealed that classifying fish fauna in the same ecoregion enables the classification of fish fauna by difference of longitudinal change of stream path in preference to difference of watersheds.
2. Comparison of the number of species in each segment-based ecoregion revealed that the total number of fish species declined according to distance from the river mouth. However, the number of freshwater species was largest in the midstream and declined upstream and downstream; this tendency is identified in three Ecoregions.
3. Indicator fish species of segment-based ecoregions reflected the fish fauna of each ecoregion in the midstream area. However, the indicator species of groups D and E of the northwest and south Kyushu Ecoregion were common.
4. Fish fauna of each ecoregion were different, but the slopes of the longitudinal sections of river dividing fish fauna were generally consistent among the three Ecoregions (group A: 1/3 500, group B: 1/1 500, group C: 1/400, group D: 1/200, group E:1/100).
5. In the south Kyushu Ecoregion, segment-based ecoregions composed of the amphitheater area (group C) were situated on the Sendai and the Oyodo rivers. Topographic characteristics of this area are a low-gradient of river bed and high altitude. Therefore, particular fish fauna were formed in the mixing of cold water fishes and fishes inhabiting low-gradient areas.
6. Applying the segment-based ecoregion concept to enable a comparison of the biological integrity of fish fauna depends on a common environmental type

between watersheds.

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