Characterizing the Historical Changes in Land Use and Landscape Spatial Pattern on the Oguraike Floodplain after the Meiji Period

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Abstract: Research on change in land use and landscape pattern is the foundation for studies exploring natural and cultural landscape of a region. This study used GIS software and utilized topographic maps to examine the changes that occurred in the Oguraike floodplain, during the time points of 1888, 1909, 1961, and 2002. The Oguraike floodplain, which was dominated by the landscape of Oguraike Pond and paddy fields in 1888, was dominated by the landscape of urban areas and paddy fields in 2002. Moreover, urban areas, cropland, paddy fields, and grasslands have become concentrated into larger patches, whilst the water bodies have become more fragmented. Overall, there has been a reduction in landscape diversity on the floodplain.

1. Introduction

Changes in land use and land spatial pattern are major contributing factors to environmental change (International Geosphere–Biosphere Programme, 1995; Li, 1996), and the complex process of change occurs through both natural processes and human intervention (Hara *et al*., 2005; Tavares *et al*., 2012; Zhang *et al*., 2010). Research on change in land use and landscape spatial pattern is important and is the foundation for studies exploring the natural and cultural landscape of a region. Diverse methods have been used to study changes in land use and landscape spatial pattern. Remote sensing using satellite imagery is used to collect data and classify features on the earth's surface（Bai *et al*., 2008; Ulbricht & Heckendorff, 1998; Zhang *et al*., 2010). Whilst topographic maps are a valuable research tool used to explore the patterns of regional historical land use and to assess the land use transfer matrix (Fujii *et al*., 2009; Matsumoto & Nishiyama, 2009; Mizunoe & Nishiyama, 2007).

This study used a geographic information system (GIS) and utilized accurate topographic maps to examine not only the detailed changes in land use that occurred in the Oguraike floodplain, such as transfer matrix, and also to explore the landscape spatial composition change in the landscape during the periods between these time points of 1888, 1909, 1961, and 2002. In addition, the mechanisms driving change and their effects were discussed. The objectives of this study were to examine: (1) how the land use and landscape pattern have changed on the Oguraike floodplain in the past 110 years; (2) the mechanisms driving these changes in different historical periods and across different geographic units.

2. Methods

2.1. EXTENT OF STUDY AREA

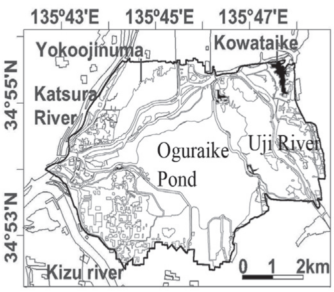

Fig 1. Extent of study area in 2002

Based on the extent of the Oguraike floodplain during the 21th year of Meiji period, and the administrative border (Ministry of land, infrastructure, transport, and tourism, 2008), we took the area extending from the confluence of the three rivers（Katsura, Uji, and Kizu Rivers）, and enclosed by the Katsura and Kizu rivers, as extent of the floodplain (Area enclosed by broad line in Fig 1). The study site lies between 34°53'0''–34°56'0''N and 135°43'0''–135°48'0''E, and covers 3666 ha.

2.2 ANALYSIS OF LAND USE CHANGE

2.2.1. Creation of A Land Use Map and Calculation of The Area Change of Each Land Use Type

The scanned historical topographic maps for the four time periods of 1888, 1909, 1961, and 2002 were georeferenced in GIS software to produce digital maps. After geographic calibration using 30 to 80 ground control points per map, the polygons for the different land-use categories were drawn. We

Table 1. Categories of landscape use type

Land use type	Contents
Urban or built-up areas	Settlements
	Roads
	Factories
Paddy fields	Paddy field
Cropland	Land cultivated for tea
	Land cultivated for mulberry
	Land cultivated for fruit
	Land cultivated for vegetable crops
Grassland	Bamboo forest
	Marginal grassland around water bodies
Water	Rivers (natural rivers with flowing water)
	The Oguraike Pond
	The Yokoojinuma Pond
	The Kowataike Pond
	Other water bodies (other ponds)
Fallow or uncertain land	Fallow or uncertain land

divided land use into six main types: urban areas, paddy fields, cropland, grassland, water, and fallow land (Table 1). To create a map with 1-m accuracy using vector data, we used large-scale maps of at least 1:25,000. We then combined the polygons into a single feature and rasterized the maps to create the land use maps for different historical periods (Fig 2). The area for each land use was calculated and presented in a table of attributes for each map. We then used the intersect analysis in the GIS software as a method of calculating the transfer matrix for land use area, which is used to reflect the source of each land use type and quantifies the loss in area for each land use type, and the type to which it is transferred (Dronova *et al*., 2011; Popp *et al*., 2009; Tavares *et al*., 2012; Zhang *et al*., 2010).

2.2.2. Exploration of Essential Factors for Land Use Change through Literature Search

This study has analyzed essential factors for morphological change in Oguraike Pond according to historical data, e.g., history of Oguraike reclaimed area (1962), custom and lifestyle of fishing village in former Oguraike area (1981), custom of Oguraike (1991), Oguraike(1991), documents for fisherman in Oguraike Pond (2002).

2.3 ANALYSIS OF LANDSCAPE PATTERN CHANGE

2.3.1. Landscape Metric Analysis

Land-use data of the Oguraike floodplain were acquired from the Section 2.2.1 and land-use data from previous years, 1888, 1909, 1961 and 2002, were manually rectified, interpreted, and classified from historical topographic maps. Based on the land-use data, landscape components were classified into five categories: urban or built-up areas, paddy fields, cropland, grassland, open water. This classification scheme was chosen because it reflects the main visual difference of landscape types obviously. And the number, size, perimeter of landscape patch was calculated and presented in a table of attributes for each map.

Based on the research question and to ensure comparability with previous studies (Ding *et al*., 2004; Li, 2004; Matsushita *et al*., 2006; Wang *et al*., 2004; Wang *et al*., 2011; Weng, 2007), a set of landscape metrics was used for evaluating landscape spatial pattern for this study, including Shannon's diversity index (SHDI), Dominance (D), Shannon's evenness index (SHEI), percentage of landscape (PLAND), edge density(ED), patch

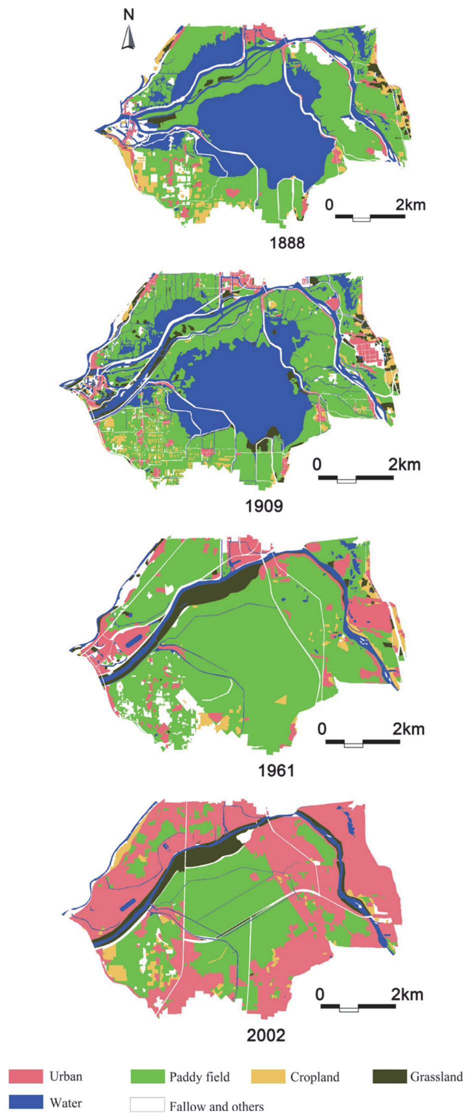

Fig 2. Land use map on the Oguraike floodplain

density (PD), and mean patch size (MPS) (Table 2). The first three metrics are indicators of landscape diversity while the latter three metrics are indicators of landscape fragmentation. Some metrics were used to examine landscape-level properties, i.e. to describe the spatial patterns of all landscape types as a whole. Other metrics were used to examine class-level properties, i.e. to describe the spatial patterns of different landscape types individually (Table 2). The selected metrics all are normalized

Table 2. Landscape metrics utilized for landscape pattern characterization

	Abbreviation	Range	*La*	*Ca*
Shannon's diversity index	SHDI	SHDI≥0, Without limit.	V	
Dominance	D	0≤ D ≤1	V	
Shannon's evenness index	SHEI	0≤SHEI≤1	V	
Percentage of landscape	PLAND	0 <PLAND≤100		V
Edge density	ED	ED> 0		V
Patch density	PD	PD > 1		V
Mean patch size	MPS	MPS> 0		V

Notes: *La* means the index used to examine landscape-level properties, i.e. to describe the spatial patterns of all landscape types as a whole. *Ca* means the index used to examine class-level properties, i.e. to describe the spatial patterns of different landscape types individually.

and hence the output values can be used to directly compare the five types of landscape patches and across the four time periods. Shannon's diversity index （SHDI）is defined as:

$$H=-\sum_{i=1}^{n} Pi*\ln(Pi) \quad (1)$$

where n is the number of landscape types and p_i is the proportion of landscape patches belonging to the ith land use type (Nagendra,2002).

Dominance (D) is calculated by:

$$D=H_{max}+\sum_{i=1}^{n} Pi*\ln(Pi)$$
$$H_{max}=\ln(n) \quad (2)$$

where n is the number of landscape types and p_i is the proportion of landscape patches belonging to the ith land use type (Nagendra,2002).

Shannon's evenness index (SHEI) is defined as:

$$SHEI=\frac{-\sum_{i=1}^{n} Pi*\ln(Pi)}{\ln(n)} \quad (3)$$

where n is the number of landscape types and p_i is the proportion of landscape patches belonging to the ith land use type (Nagendra,2002).

Percentage of landscape (PLAND）is calculated by:

$$PLAND=(PS/A)*100\% \quad (4)$$

Where PS is the area of one certain landscape (ha) and A is the total area of the study site (ha) (Nagendra,2002).

The edge density index(ED) is calculated by:

$$ED=P/PS \quad (5)$$

where P is the perimeter of the patch (m) and PS is the patch size (ha) (Li,1996).

The patch density (PD) is calculated by:

$$PD=(N/PS)*100 \quad (6)$$

Where PS is the patch size (ha), and N is the number of patches(Weng,2007).

The mean patch size (MPS) is calculated by:

$$MPS=PS/N \quad (7)$$

Where PS is the patch size (ha), and N is the number of patches(Li,1996).

2.3.2. Patterns of landscape diversity in response to changes in proportion of land use

According to the formula of the landscape pattern index listed in 2.3.1, the formulas referring to landscape diversity are all related with the percentage of landscape patches in a certain region. In order to investigate the inner reasons of changes in landscape pattern on the floodplain, we carried out the bivariate correlation analysis using SPSS between the Shannon's diversity and Percentage of landscape (PLAND), that were PLAND _Urabn, PLAND_Paddy field, PLAND_Cropland, PLAND_Grassland, and PLAND_Water.

3. Results

3.1 EVALUATION OF LANDSCAPE COMPONENT DISTRIBUTION BASED ON A ANALYSIS OF LAND USE CHANGE ON THE OGURAIKE FLOODPLAIN

3.1.1 Landscape component distribution change

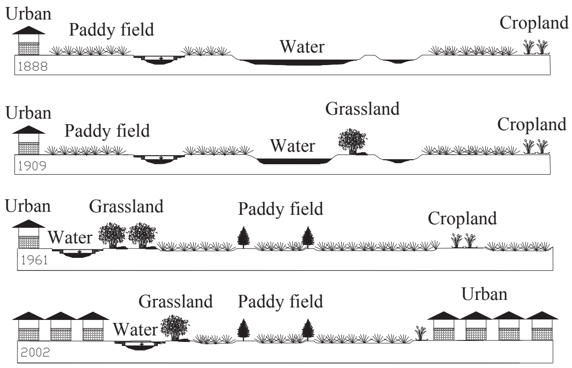

Fig 3. Models of landscape composition on the Oguraike floodplain

According to the land use maps (Fig 2), we drawn the models of the landscape components composition in the direction from North to South of the floodplain. In 1888, the large area of open water was the typical landscape component on the floodplain (including the Oguraike Pond, Yokoojinuma Pond, and Kowataike Pond, rivers, and other waters) (Fig 2 and Fig 3), and almost accounted for 38% of the total floodplain (Fig 4). Vast expanses of paddy fields surrounded the Oguraike Pond (Fig 2 and Fig 3), representing 41% of the total floodplain (Fig 4). Croplands were located to the east of floodplain (Fig 2 and Fig 3), which, according to topographic maps, included orchards, tea plantations, and mulberry plantations. Only 4% of the whole area was urban or built-up, the majority of which was settlements (Fig 4). In addition to the three well-known ponds (Oguraike, Yokoojinuma, and Kowataike), there were several small ponds adjacent to rivers (Fig 2).

In 1909, the landscape throughout the floodplain was similar to that in 1888. The water area and paddy fields were still the two main types of landscape components (Fig 3).

In 1961, the land use composition had changed greatly in the Oguraike floodplain by reclamation of the large area of water (Fig 3). The coverage of paddy fields was the typical landscape and had increased to 65% of the whole area (Fig 4). The urbanization primarily happened in the districts of Fushimi, Yodo, and Uji. Grassland had also emerged on the north bank of the Oguraike reclamation area as a result of a reduction in the number of tributaries (Fig 3).

In 2002, urban areas became the largest landscape component (48% of the floodplain) (Fig 4), followed by paddy fields (35%), which had been enclosed by urbanization (Fig 3).

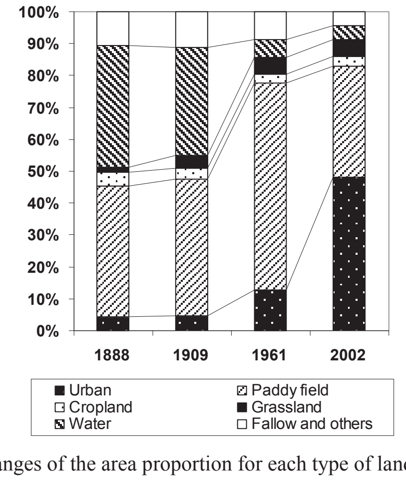

Fig 4. Changes of the area proportion for each type of land use on the Oguraike floodplain

3.1.2 Direction of the main landscape component change on the Oguraike floodplain

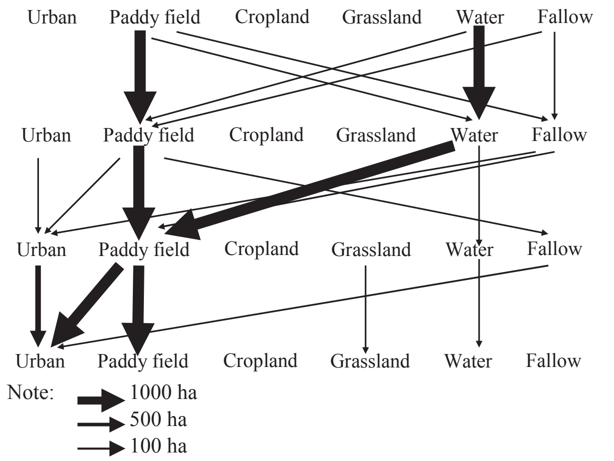

Fig 5. Land use transfer express (transfer area is more than 100 ha)

The change, or transfer, from one type of land use category to another over time can be analysed using a transition or transfer matrix. In order to reduce error, I focused on the transfer trend with transfer area more than 100 ha (Fig 5).

During 1888–1909, there were even few land use types that transferred into one of other land use types. The typical water and paddy field landscape during this period remained by transferring from themselves (Fig 5).

During the period 1909–1961, the typical landscape of expanding paddy fields were mainly converted from various types of water land use (Fig 5): 1183 ha of paddy field remained; in addition 972 ha of the water bodies, plus a small area of other land use were converted into paddy fields.

From 1961 to 2002, the most significant change was the conversion of other types of land use to urban or built-up landscape (Fig 5). A total of 423 ha of original urban area remained, but in addition 1018 ha of paddy fields, some of the other landscape components was converted to urban land.

3.2 QUANTITATIVE ANALYSIS OF LANDSCAPE PATTERN CHANGE ON THE FLOODPLAIN

3.2.1 Landscape-level metric analysis of landscape diversity on the Oguraike floodplain

The dominance value reached to its lowest point in 1909. It meant that regional landscape was complex in 1909, in which diverse types of landscape had dominant status (Fig 6). The dominance value reached to highest point in 1961. It meant the regional landscape was influenced and dominant by very few types of landscape.

Shannon's diversity index and evenness index change presented a similar tendency. On the floodplain at the first period of this study, in 1888, they were closest to that of 1909, whilst landscape diversity and evenness in 1961 were similar to that in 2002(Fig 7, Fig 8).

Overall, the regional landscape was most diverse in 1909, and was at its lowest point in 1961. And the regional landscape diversity of the Oguraike floodplain has decreased from 1888 to 2002.

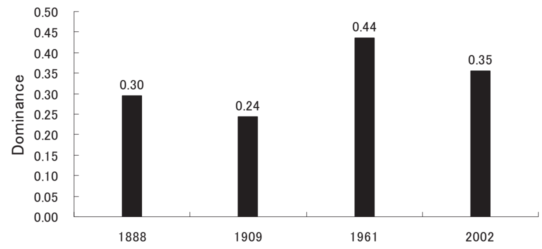

Fig 6. Dominance change on the Oguraike floodplain

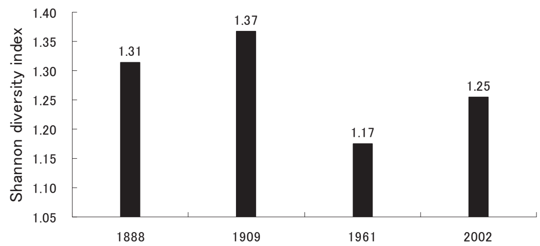

Fig 7. Shannon diversity index change on the Oguraike floodplain

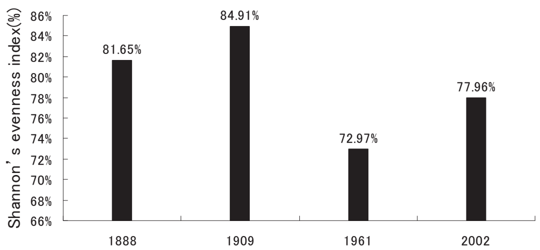

Fig 8. Shannon's evenness index change on the Oguraike floodplain

3.2.2 Class-level metric analysis of landscape heterogeneity on the Oguraike floodplain

The landscape spatial pattern on the Oguraike floodplain has changed as a result of the transfer of land use type from one category to another. According to the edge density of the five main landscape patches, urban areas, cropland, paddy fields, and grasslands formed denser patches and were less fragmented since 1909. However, the water landscape patches became more fragmented over time (Fig 9).

With regards to mean patch size (Fig 10), the mean area of patches of cropland, grassland, and urban increased, whilst the mean area of patches of water decreased over time. According to the curve for mean patch size of paddy field, the value reached its peak in 1961 and fell to its bottom in 2002.

The density of patches of urban, cropland, and grassland decreased since 1909; the density of water patches increased gradually and slightly; the density of patch of paddy field was highest in 2002, and was lowest in 1961(Fig 11).

Overall, landscape fragmentation was greatest in 1909, and was at its lowest in 1961. Urban areas, cropland, paddy fields, and grasslands formed denser patches and were less fragmented since 1909. However, the water landscape patches became more fragmented through the study period.

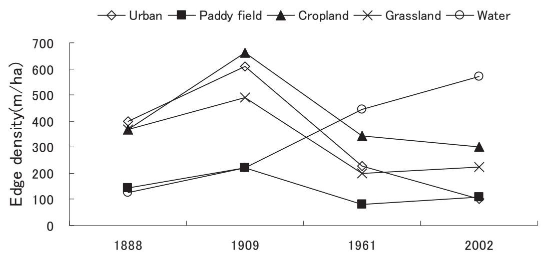

Fig 9. Edge density change for each type of landscape on the Oguraike floodplain

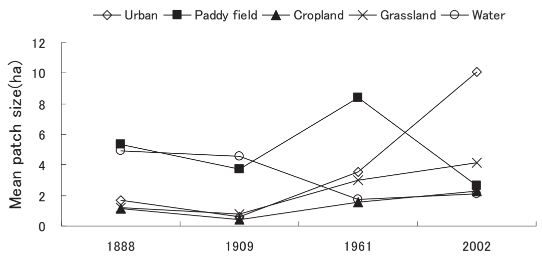

Fig 10. Mean patch size change for each type of landscape on the Oguraike floodplain

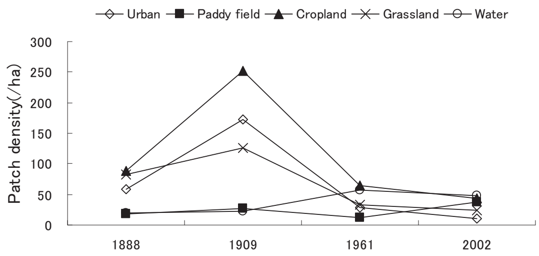

Fig 11. Patch density change for each type of landscape on the Oguraike floodplain

4. Discussion

4.1 SOCIAL FACTORS CAUSING CHANGES IN COMPOSITION OF LANDSCAPE COMPONENT

According to historical documents, prior to 1900 the Oguraike Pond was connected to the Uji River system and frequent flooding of this river resulted in the Oguraike Pond being a well-known reservoir (Institute of History of Kyoto, 1991; Institute of History of Uji, 1991; Institute of History of Uji, 2002), and it has rich culture of fishery (Fukuda, 1981). The landscape in the year 1888 could present this kind of typical suburban wetland system of Oguraike Pond and its surrounding floodplain at that time (Fig 12).

At the second timing point of 1909, the Uji River had been diverted and there was a subsequent reduction in the volume of water flowing into the Oguraike Pond (Yoshita, 1962). Consequently, the area of the water contracted and was transferred into paddy fields. The area of paddy fields landscape expanded. However, there were small changes in the composition of other types of land use on the floodplain, and the Oguraike floodplain still presented complex wetland landscape (Fig 12).

During the war time, in order to increase the food production, and reduce the risk of flood and malaria, the wetlands reclamation projects begun in Japan. Under this social background, the Oguraike and Yokoojinuma ponds were also reclaimed and natural water bodies were converted into paddy fields since 1934 (Bando *et al*.,2001). The landscape of Oguraike floodplain in 1961 could stand for the scenery and land use composition of the floodplain after reclamation. There was the extension of the paddy fields (Fig 12).

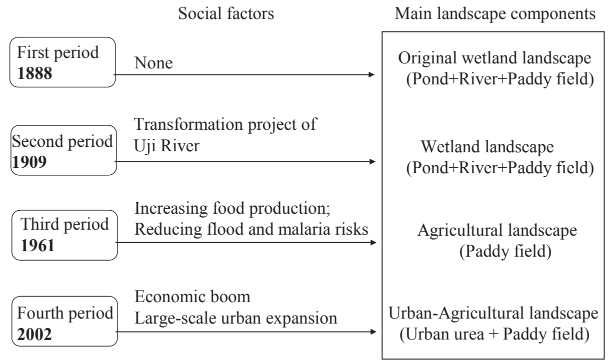

Fig 12. Social factors causing changes in landscape

Since the 60 years of the last century, an economic boom has led to large-scale urban expansion in the whole country of Japan (Kadoya *et al*., 1980), and the demand for land for housing and industry increased dramatically. The Oguraike floodplain was also affected by this influence. The landscape in 2002 could express the land use composition status on the Oguraike floodplain and the result affected by these social factors. It resulted in the area of urban and built-up land accounting for more than half of the entire region of Oguraike (Fig 12).

4.2 PATTERNS OF LANDSCAPE DIVERSITY IN RESPONSE TO CHANGES IN PROPORTION OF LAND USE

Bivariate correlation analysis (Table 3) revealed that the attribute of SHDI was negatively correlated with PLAND_Grassland, PLAND_Urban, and PLAND_Paddy field, and was positively correlated with PLAND_Water, and PLAND_Cropland (The correlation coefficients showed no statistical significance due to a small number of samples).

It means that, during the period from 1888 to 2002, the exploration and human intervention led to growth of land use of urban, paddy field, and grassland, and led to reduction of natural water habitats on the Oguraike floodplain. This caused a decline in the diversity of regional landscape.

Table 3. Pearson's correlation coefficients of percentage of five types of landscapes (PLAND) to landscape diversity (SHDI)

	Urban	Paddy field	Cropland	Grassland	Water
Correlation Coef.	-0.35	-0.67	0.64	-0.56	0.84
Sig.(2-tailed)	0.65	0.33	0.36	0.44	0.16
n	4	4	4	4	4

5. Conclusions

Following over 110 years of natural and human interference, the composition of the different types of land use and the spatial form of the landscape have undergone dramatic changes on the Oguraike floodplain. The floodplain, which was once dominated by the water landscape and paddy fields, is now dominated by urban or built-up areas and paddy fields.

With regards to the landscape pattern on the Oguraike floodplain, the regional landscape was most diverse in 1909, and was at its lowest point in 1961 by the increase of paddy fields. Overall, the landscape diversity of the Oguraike floodplain has decreased from 1888 to 2002. Urban areas, cropland, paddy fields, and grasslands formed denser patches and were less fragmented since 1909. However, the water landscape patches became more fragmented through the study period. The landscape diversity was significantly affected by the changes of percentage of landscape on the Oguraike floodplain, especially in the degree of reclamation at first, of following urbanization and the deterioration of natural water habitat.

Endnotes

1. Four periods of topographic maps: (1) maps of Uji area surveyed in 1888 and Yodo area surveyed in 1890 (1:20000; Land Survey Authority of Japan）; (2) maps of Uji and Yodo area surveyed in 1909 (1:20000; Land Survey Authority of Japan,）; (3) maps of Uji area, Yodo area, the southeast area, and the southwest area of Kyoto prefecture amended in 1961 (1:25000, The Geospatial Information Authority of Japan）; (4) maps of Kyoto and Osaka prefecture surveyed in 2002 (1:25000, The Geospatial Information Authority of Japan）.

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