Changes in land cover and grassland area over the past 120 years in a rapidly urbanised area in Japan

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Abstract

In wet temperate regions, human activity has played an important role in shaping the size and distribution of grasslands. We examined change in land cover type and grassland area in a 9.2 × 22.3 km area of northern Chiba Prefecture, based on historical maps and documents for four time periods (1880s, 1950s, 1980s and 2000s). In the 1880s, conifer forests occupied the largest area (43.1%) amongst land cover types and grasslands accounted for 4.2% of the total area. However, literature available from the 1880s suggests that the understorey of conifer forests may have served as additional habitat for grasses. Thus, the habitat of grassland species is suggested to have covered up to 54% of the study area during this time period. By the 1950s, much of the grassland present in the 1880s had been changed to agricultural fields and paddies and grassland area had reduced to 2.9%. Residential development prior to and during the 1980s led to the conversion of forests and agricultural fields to grassland, increasing the grassland area to 11.6% of the study area. Finally, in the 2000s, grasslands had declined to 6.0% of the study area, likely due to conversion to residential areas. Despite these changes over time, 1.5% of the study area has remained as native forest or grassland for over 120 years. The spatial data presented herein are useful for conservation planning and studying the effect of historical land use change on biodiversity.

Keywords

Land use change, Historical map, Time series data, Biodiversity conservation, GIS, Japan

Introduction

Grasslands are critical to the maintenance of biodiversity and ecosystem services (Safriel et al. 2005). In wet temperate zones, where climax vegetation is represented by forest communities, the establishment and longevity of grassland is strongly influenced by human activities and social attitudes (Squires et al. 2018). Although the historical change of grassland has been studied in European countries and the USA by many researchers (Xiao et al. 2015, Feurdean et al. 2016, Spencer et al. 2017, Wimberly et al. 2017, Manton and Angelstam 2018) , there are few studies in Japan (Sprague et al. 2000, Ichikawa et al. 2006, Koyanagi et al. 2009).

Natural grasslands in Japan are distributed in limited areas such as alpine zones, coast and riparian areas (Ushimaru et al. 2018). On the other hand, semi-natural grasslands, which have been maintained by human activities, such as mowing and/or burning, are widely distributed from mountains to lowlands (Ushimaru et al. 2018). According to distribution of Andosols, extensive human efforts directed towards the maintenance of grasslands are estimated to have begun between several thousand to 10,000 years ago (Ogura 2012); prior to the modernisation of agriculture, this maintenance activity was exerted to provide grazing for livestock, fertiliser and roofing materials (Hayashi and Minami 1951, Okubo and Tsuchida 2007, Takeuchi et al. 2001). In recent years (after the 1960s), grasslands have been decreasing throughout Japan due to the abandonment of management practices, expansion of conifer plantations and urbanisation (Ogura 2012, Okuro et al. 2015).

Grassland disappearance is associated with degradation of biodiversity and the ecosystem services that it provides, such as groundwater supply, air temperature cooling and maintenance of cultural values related to grassland systems (Bullock et al. 2011, Takahashi et al. 2011).Species composition and richness of semi-natural grasslands can influence to ecosytem functions (Tilman et al. 2002). Thus, the clarification of the factors affecting species composition of semi-natural grasslands is an important issue. Recently, it was suggested that species composition of grassland is influenced by historical land use. For example, Lindborg and Eriksson (2004) showed that the present species richness is better explained by landscape structures 50 to 100 years ago than by the present landscape structures. Therefore, to plan for effective conservation and utilisation, it is necessary to understand not only the current distribution of grasslands, but also how they have transitioned over time.

In northern Chiba Prefecture, Japan, large grassland areas were historically used as pasture (“Inzai-maki”) during the Edo era (1603–1868) and were under government control during that time (approximately 300 years ago; Aoki 2003). Beginning in the 1860s, at the end of the Edo era, agriculture, industry and social structures began to change dramatically. Around this time, colonisers from Tokyo created new agricultural land (Amano 2003, Aoki 2003). After World War II, grasslands were no longer used as they had been historically, as a result of modernisation of agricultural methods and lifestyles. During this

same period, afforestation of coniferous trees was promoted by national afforestation policies. However, many of these afforested areas were not utilised for forestry and were abandoned. After the 1980s, development of large roads and railways progressed and large-scale residential areas were created, mainly in upland areas, for commuters travelling from Chiba Prefecture to Tokyo.

In this study, digitised historical maps and documents were used to examine grassland distribution and areas over 120 years in northern Chiba Prefecture. Digitised historical maps are tools that may prove highly valuable for acquiring data regarding land use changes. These data, which are closely relating with local biodiversity, are particularly valuable within the present study area, as local governments are currently formulating a regional biodiversity conservation strategy therein.

Methods

We focused on the northern Chiba Prefecture, one of the areas with largest semi-natural grassland in Japan (Aoki 2003). Although the semi-natural grasslands in this area have long-history (at least 1000 years; Aoki 2003), the land-use change is very severe in the last 100 years because the location is close to the national capital, Tokyo. The study area was 9.2 × 22.3 km in size, corresponding to the “Shiroi” and “Kobayashi” areas shown in a 1:25,000 map of Geospatial Information Authority of Japan (Fig. 1). This area includes flat uplands 20–50 m in elevation, flat lowlands 1–10 m in elevation and small valleys at the edges of uplands. The altitude data used the 5 m mesh DEM provided by Geospatial Information Authority of Japan.

We created land cover maps for four time periods (the 1880s, 1950s, 1980s and 2000s) using the ArcGIS version 10.2 (ESRI, Japan) from the following data sources:1880s, Rapid Survey Maps from 1880–1882 with a 1:20,000 scale (Sprague and Iwasaki 2006); 1950s, a topographic map surveyed in 1952 with a 1:25,000 scale, published by the Geospatial Information Authority of Japan; 1980s, the 3rd National Surveys on the Natural Environment vegetation map, based on a 1983 survey with a 1:50,000 scale (Japan Ministry of Environment 2008); and 2000s, the 6th and 7th National Surveys on the Natural Environment vegetation maps, based on a 2008 survey with a 1:25,000 scale (Japan Ministry of Environment 2008). We used the projected coordinate system to Japan Plane Rectangular CS IX Mercator (EPSG: 2451) before determining land cover type areas for each time period.

For the 1880s and 1950s, we created land cover polygons using digitised historical maps. Land cover types were classified into nine categories: residential area, paddy, agricultural field, bamboo forest, broad-leaf forest, conifer forest, grassland, wetland and others (Suppl. material 1). To compensate the information obtained from the historical maps, we used a Reconnaissance Note ("Teisatsuroku"; Rikugun-bunko 1881), which included supplemental information of the Rapid Survey Maps. The note records the microclimate, landscapes, forest conditions, resources of each village, the character of the people etc. We extracted information related to vegetation from it. In this literature, there were several descriptions of

the grass-harvesting from the forest floor. Similarly, the forest floor was still bright around 1950s (Suka et al. 2019). Thus, for the 1880s and 1950s periods, areas classified as ‘grassland’, ‘conifer forest’ and ‘broad-leaf forest’ were combined into the category of ‘grassland in a broad sense’.

For the 1980s and 2000s, we used the same nine categories listed above and assigned features unique to these decades to one of the nine categories. Specifically, places appearing as “pre-development land” in these decades were included in the ‘residential area’ category, as they would have been developed shortly after the maps were created. We also used ‘residential area’ to represent golf courses, as these areas are not suitable habitat for grassland species (Kurita and Yokohari 2000). In the 2000s map, golf courses and lawns were not distinguished, but we separated these two land uses using Google Earth imagery (Google Inc. 2013) and included lawn in the grassland category.

After assigning all polygons to land cover types, we calculated the total area of each land cover category for the four time periods using a geometrical calculation, performed using ArcGIS. We also established the age of grasslands in a broad sense that were present in the 2000s. Age was categorised into four classes, i.e. grasslands established after the 1980s (< 20 years), between the 1980s and 1950s (20 – 50 years) and between the 1950s and 1880s (50 – 120 years), as well as grasslands that had already been established by the 1880s (> 120 years).

Results

Land cover change

In the 1880s, conifer forest was the largest land cover type, accounting for 43.1% of the total study area (Fig. 2a and Fig. 3); the value for grassland area was 4.2% (865 ha; Fig. 3). Grassland, in a broad sense, accounted for 53.8% of the study area in the 1880s.

By the 1950s, grassland area was greatly reduced (Fig. 2b) and occupied only 2.9% of the total area (Fig. 3). Conifer forest had also decreased, although it remained the largest land cover type, at 33.7%. We again estimated the area of ‘grassland in a broad sense’, given the high dependency on grassland products during this period (Hayashi and Minami 1951); the value thus obtained was 38.3%. Between the 1880s and 1950s, the land cover type ‘agricultural field’ increased to 26.0%.

In the 1980s, grassland area increased (Fig. 2c) to 11.6% of the total area, in accordance with the formation of large clusters of grassland. In contrast, conifer forest and agricultural field cover reduced to 19.0% and 20.4%, respectively. In this time period, the area corresponding to developments, i.e. the 'residential area' category, doubled as compared with 1950s, to 17.0% of the total area.

In the 2000s, a number of previously existing upland grasslands had disappeared (Fig. 2d) and grassland area had decreased to 6.0% (Fig. 3). The 'residential area' category

accounted for 30.2% of the total area and, thus, was the largest land cover type amongst all categories. Through the four time periods examined here, ‘paddy’ was mainly distributed in the lowlands (Fig. 2). The rich paddy area was largely stable, at roughly 20% of the total area, but had increased by the 2000s, relative to the 1880s.

Patterns of grassland area

Between the 1880s and 1950s, conifer forests, that had dominated the landscape in the 1880s, declined due to the development of agricultural fields. Over this period, 285 ha (32.9%) and 264 ha (30.5%) of grasslands that existed in the 1880s were converted to paddy and agricultural fields, respectively (Suppl. material 2a). Between the 1950s and 1980s, conifer forests and agricultural fields, that previously occupied large areas, were converted to grassland or residential areas (Suppl. material 2b). Most of these grasslands, however, were converted into residential areas between the 1980s and 2000s (Suppl. material 2c, Fig. 3). Conifer forests and agricultural fields were also developed into residential areas during this time.

The additional category of 'grassland in a broad sense' occupied 11,059 ha in the 1880s, but it was only 316 ha in the 2000s (Fig. 4a). The grassland that have been maintained for over 120 years occupied about 25% of grasslands area in the 2000s (Fig. 4b). Since the 1980s, more than 70% of the grassland area changed to another land use type. As a result, young grasslands, less than 20 years old, accounted for half of the grassland area existing in the 2000s. The grasslands present in the 2000s were colour-coded by age and indicated on the map (Fig. 4c). Grassland with a short history (< 20 years old) were widely distributed on the upland. Grassland with a long history (> 120 years old) had one large cluster on the west side.

Discussion

In this study, we confirmed that the area occupied by grasslands has changed over time in response to a decrease in demand for grass resources due to changes in fuel and fertiliser and an increase in residents due to population concentration in Tokyo. The Edo era policies, persisting in the 1880s, likely influenced the large amount of grassland in the study area during that time. Specifically, the large semi-natural grassland had been maintained because the pasture was managed for the purpose of fostering agricultural and army horses (Aoki 2003). The Reconnaissance Note states that at least 2,339 horses were kept in villages within the study area. This suggests that the grassland area may have been roughly 2.7 times larger than our estimation, as one hectare of grassland was needed to keep one horse (Osako 1937). The information in the Reconnaissance Note suggested that a larger area of grassland plant habitat was available during the 1880s. After that period, the development of agricultural lands (agricultural fields and paddies) was advanced to support the growing Japanese population, but it is probable that grassland areas necessary for living and grassland-dependent agriculture were maintained.

The time period between the 1950s and the 1980s corresponded to Japan's period of rapid economic growth and modernisation of agriculture and daily life; thus, grassland in a broad sense area was rapidly lost, as has also been documented in other regions of Japan (Inui 1996, Shirai 2005). In the 1960s, a governmental town development plan, referred to as "New Town Development", was implemented around the suburbs of Tokyo. The focal area of this study is the site of the "Chiba New Town Development" and, while construction in Chiba was delayed relative to other New Town Developments, it progressed through the 1980s. This is reflected in the increase in residential areas and reduction of the area of grassland in a broad sense during this time.

In addition, understorey conditions are thought to have greatly changed between past and present (Ogura 2012, Suka et al. 2019). In the 1960s, a major shift in fuel sources from wood to fossil fuels (i.e. the "fuel revolution") greatly changed the use of natural resources by local people (Murao 1982). Prior to the fuel revolution, the major forest types were coppice woodlands, dominated by *Quercus* and pioneer forest of *Pinus*; the understorey in these woodlands is thought to have had enough light availability to grow grassland plants (Ogura 1992). After the fuel revolution, the use of such forests diminished and vegetation succession progressed. At the same time, the Japanese government promoted *Cryptomeria* afforestation policies. For these reasons, the majority of forest understoreys likely became much darker and the habitat and grassland plants in these areas appear to have been largely lost.

The pattern of decrements of forests and grasslands and increment of residential areas are thought to have occurred in various regions in Japan (Himiyama et al. 1995). This is in contrast to European countries, where development into farmland is a major land cover change from semi-natural grassland (Cousins 2001, Johansson et al. 2008).

Conservation and future grassland research

This study showed that current grasslands in northern Chiba Prefecture have various historical backgrounds (Fig. 4). The differences in historical background (e.g. grassland continuity) can be useful indicators of species diversity and/or ecosystem functions (Cousins and Eriksson 2002, Reitalu et al. 2012). In fact, some recent studies have suggested that past land use and landscape factors strongly influence the species composition of current grasslands (Lindborg and Eriksson 2004, Kuussaari et al. 2009). Here, we showed that only 1.5% of grasslands (316 ha) in the focal area were preserved from agricultural conversion or residential development for the past century. In our next research, the historical effect on plant diversity of remnant grasslands will be analysed together with the effects of local management and surrounding environment. The digital maps made here are useful to make land-use plans, as well as necessary for the study.

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Conflicts of interest

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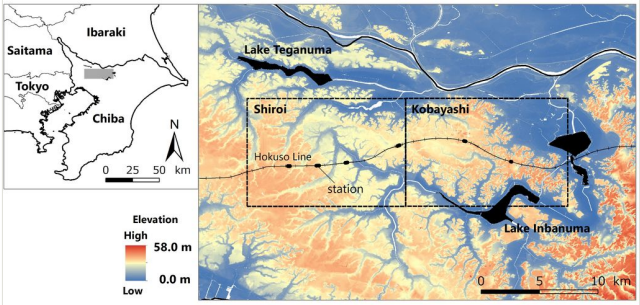

Figure 1.

Survey area. The subjects of the survey were "Shiroi" and "Kobayashi", which are indicated by broken lines. Black circles indicate train stations. The projected coordinate system was used as Japan Plane Rectangular CS IX (EPSG: 2451).

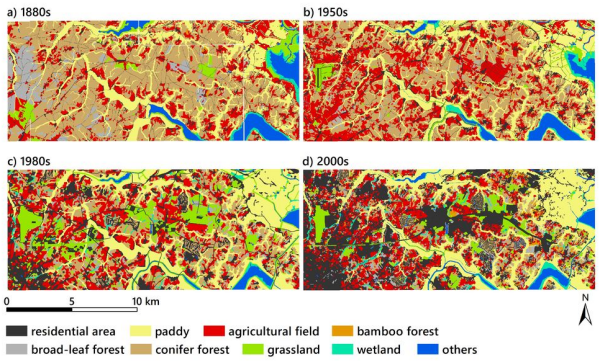

Figure 2.

Land cover maps for the four time periods in northern Chiba Prefecture: a) 1880s, b) 1950s, c) 1980s and d) 2000s.

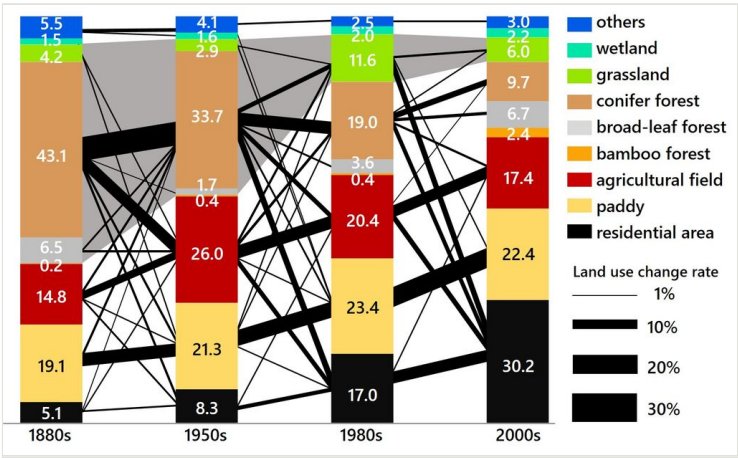

Figure 3.

Prevalence of, and changes in, land cover types. The value in each bar indicates the percentage (%) of each land cover type. The range of the ‘grassland in broad sense’ land use category is denoted by the shaded area. The black line connecting the left bar to the right bar shows the change of land use between the periods. The thickness of the line corresponds to the proportion of the area changed (with respect to the whole survey area). When land cover changed less than 1% of the whole, the line was omitted.

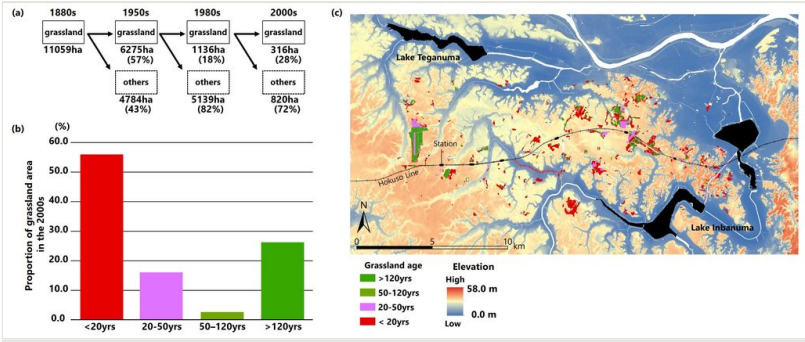

Figure 4.

a) Change pattern of "grassland in a broad sense" from the 1880s. The "grasslands" of the 1880s and 1950s include broad-leaf forests and conifer forests and the "grasslands" since the 1980s include only grassland. () shows the proportion of the area occupied in the grassland of the previous periods. b) Estimated age of grasslands in a broad sense existing in the 2000s (1,229 ha). c) Distribution and age of the remaining grassland in the 2000s.

Supplementary materials

Suppl. material 1: Land cover type used in historical maps of each period

Authors: Akira Noda, Akihiko Kondoh, and Jun Nishihiro
Data type: Table
Brief description: Correspondence of the legend of nine land cover types and each time periods.
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Suppl. material 2: Land cover changes over time in northern Chiba Prefecture.

Authors: Akira Noda, Akihiko Kondoh, and Jun Nishihiro
Data type: Table
Brief description: Values in parentheses indicate the ratio of the changed area relative to the total study area. The largest land use change is shown in bold: a) from the 1880s to 1950s, b) from the 1950s to 1980s and c) from the 1980s to 2000s.
Download file (45.50 kb)