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Evaluating restoration success of a 40-year-old urban forest in reference to mature natural forest

Takeshi Sasaki[a,b,c], Hiroaki Ishii[b,*], Yukihiro Morimoto[c]

[a] *Graduate School of Technology, Industrial and Social Sciences, Tokushima University, Tokushima 770-8506, Japan*
[b] *Graduate School of Agricultural Science, Kobe University, Kobe 657-8501, Japan*
[c] *Faculty of Bio-environmental Science, Kyoto Gakuen University, Kameoka, Kyoto 621-0022, Japan*

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ABSTRACT

We assessed whether forest restoration was successful in Expo '70 Commemorative Park in Osaka Prefecture, Japan, which was planted in the 1970s with native late-successional tree species. Detailed survey and analysis of species composition, stand vertical stratification, and forest dynamics, including comparison with a reference, natural late-successional forest, were conducted. The restoration plots had grown to larger basal area compared with the reference plots, however, this was a consequence of very high densities of the overstory trees due to low self-thinning rate. Stand vertical structure of the restoration plots was biased toward overstory layers, causing high mortality of understory trees and shrubs. Because there are no mature forests near the restoration site that could act as a seed source, abundance and diversity of understory trees are likely to continue decreasing in the restoration plots, resulting in single-layered forest structure similar to those of monocultures and even-aged forests. Many seedlings of exotic species emerged in the restoration plots and this could lead to a plagiosere where exotic species dominate the vegetation inhibiting regeneration and growth of native species. Ordination analysis using different measures, basal area and abundance, showed apparently contradicting results, suggesting that multiple criteria are needed to evaluate forest restoration success. Our results indicate restoration of mature, late-successional forest cannot be achieved by simultaneous planting of native species. To sustain urban forests into the future, we must conduct long-term monitoring and management referencing natural forest structure and dynamics.

1. Introduction

Globally, the proportion of the world's population living in urban areas has reached 50% (United Nations, 2008), and it continues to increase. Urban forests play a significant role to improve urban environmental quality and human health (Nowak and Crane, 2002). Urban forests provide various ecological services, such as carbon sequestration (Nowak and Crane, 2002), climate regulation including heat island mitigation (Hardin and Jensen, 2007), aesthetic values (Tyrväinen et al., 2003), and habitat for a variety of species (Alvey, 2006; Sandström et al., 2006). However, it is difficult to sustain forest ecosystem functions in harsh urban environments and this has led to degradation of urban forest quality in many cities (Yang et al., 2005; Ishii et al., 2010; LaPaix and Freedman, 2010; Jim, 2013; Ballantyne et al., 2014). Thus forest restoration projects have been conducted in urban areas around the world in an effort to sustain healthy urban forests (Morimoto et al., 2006; Ruiz-Jaén and Aide, 2006; Oldfield et al., 2013; Climate summit, 2014).

As goals of the forest restoration, many projects pursue forests comprising native tree species indigenous to the region (Ruiz-Jaén and Aide, 2005b; Hotta et al., 2015; Almas and Conway, 2016; Gatica-Saavedra et al., 2017). These forests are expected to be self-sustaining and resilient to perturbation (Ruiz-Jaén and Aide, 2005a; Morimoto et al., 2006). However, it remains largely unknown whether such restorations will actually produce mature native forest (Oldfield et al., 2013). Despite the importance of long-term monitoring and management toward the goals, most studies monitoring the development of native urban forest restoration projects report progress within five years after planting (Ruiz-Jaén and Aide, 2005a; Oldfield et al., 2013). Very few studies have explored long-term forest dynamics by repeated monitoring after planting (but see Hotta et al., 2015).

In Japan, Environmental Protection Forests have been planted in urban and industrial areas since 1970s. These forests aimed to restore "potential natural vegetation" (*sensu* Miyawaki, 2004) of the region. In such forests, tree saplings, mainly composed of native late-successional tree species, are planted at high densities (20,000–120,000 trees/ha) on

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[*] Corresponding author.
E-mail address: hishii@alumni.washington.edu (H. Ishii).

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improved soil in order to achieve canopy closure within a short period (Nakashima et al., 1998; Miyawaki, 2004; Nakamura et al., 2005). The prevalence of this method was based on thinking that mature, climax forest, most of which had been lost by drastic urbanization in Japan during 1950-60s, should be conserved and restored (Morimoto et al., 2006). Initial assessment indicated success of this restoration method in terms of vegetation cover, as a result of rapid tree growth to the height of 9–11 m 15 years after planting (Murata and Komaki, 2001).

However, the concept of forest conservation and restoration has changed over time due to accumulation of new scientific knowledge. Recently, in addition to clearly defined quantitative measures, such as canopy height and vegetation cover, the importance of integrative measures of ecosystem quality, such as biodiversity and ecosystem services have been revealed (Mace, 2014; Mori, 2017). Intrinsically, late-successional natural forests are composed of various tree species and uneven-aged trees, and have more complex structure and higher productivity compared with monocultures and even-aged forests (Ishii et al., 2004). Structural complexity and tree-trait diversity increases vertical stratification and reduces niche overlap (Ishii et al., 2013; Dănescu et al., 2016), contributing to increasing biodiversity of a variety of organisms by generating various habitats (MacArthur and MacArthur, 1961; Brokaw and Lent, 1999; Ishii et al., 2004), and also enhances resilience to disturbances (Pretzsch, 2014). Therefore, to evaluate the success of natural forest restoration, various parameters of forest structure should be measured, including not only aggregate measures such as forest height and vegetation cover, but also species composition and vertical structure (Rebele and Lehmann, 2002; Marziliano et al., 2013). Monitoring forest dynamics such as tree growth, mortality, and recruitment are also important for future management and strategies for long-term sustainability (Robinson and Handel, 2000; Morimoto et al., 2006; Oldfield et al., 2013). In addition, changes in forest structure need to be compared with that of reference sites to evaluate the level of restoration success (Hobbs and Norton, 1996; Ruiz-Jaén and Aide, 2006).

In this study, we assessed whether forest restoration was successful in Expo '70 Commemorative Park in Osaka Prefecture, Japan. The urban forest within Expo '70 Park (total park area = 130 ha) was planted in the 1970s and represents a pioneering example of the Environmental Protection Forests in Japan (Nakamura et al., 2005; Morimoto et al., 2006). In this site, long-term, repeated monitoring revealed that canopy closure was achieved by 30 years after planting, and stand volume growth could be promoted by improving soil drainage (Morimoto and Kobashi, 1985; Njoroge and Morimoto, 2000; Sasaki et al., 2007). However, detailed survey and analysis of the forest structure and dynamics, including comparison with reference forest, has not been conducted. The purpose of this study is to evaluate restoration success of this forest using various measures including species composition, stand vertical stratification, and forest dynamics and to compare these measures with those of a reference natural forest in the same vegetation zone.

2. Methods

2.1. Study sites and vegetation survey

The restoration site is Expo '70 Commemorative Park (135°31–32′E, 34°47–48′N, 40 ~ 61 m ASL), located in Suita City, Osaka Prefecture, Japan (Fig. 1a). The total area of the park is about 130 ha. This region is in the warm-temperate zone, where evergreen broad-leaved forest is regarded as the inherent natural vegetation (Miyawaki et al., 1984). The area was covered with semi-natural secondary forest until 1960s, followed by large-scale clearing for the World Exposition in 1970. After the Exposition, the site was mounded with imported local soils from the neighboring hills by filling and grading operations, and re-vegetation was conducted from 1972 to 1976. The forest restoration area, which occupies about 27 ha in the park, was designed to achieve climax forest, and saplings of various tree species, mainly composed of evergreen broad-leaved trees such as *Quercus glauca* Thunb. ex Murray, *Castanopsis cuspidata* (Thunb. ex Murray) Schottky, *Castanopsis sieboldii* (Makino) Hatusima ex Yamazaki et Mashiba, *Machilus thunbergii* Sieb. et Zucc., and *Cinnamomum camphora* (L.) Presl, *Camellia Japonica* L., and *Photinia glabra* (Thunb.) Maxim., were planted. These include canopy, sub-canopy, and shrub species, many of which are late-successional species native in this region (Miyawaki et al., 1984). Some species, however, are not precisely native. For example, it was revealed by later studies that *M. thunbergii* is native to regions nearer to the coast (Hattori, 1992), and *C. camphora* is native in regions further south than Expo Park (Tabata et al., 2004; Ishii et al., 2016). Along the circumference of the park, tree species which have high tolerance to air pollution were planted, including *Quercus phillyraeoides* A. Gray, *Pittosporum tobira* (Thunb. ex Murray) Aiton, and *Myrica rubra* Sieb. et Zucc., because the air pollution was severe in Japanese urban areas in 1970s. After the Expo, urbanization has progressed in the area surrounding the park. Presently, the distance from the nearest forest is about 2.5 km. Additional details on this park have been reported in previous studies (Morimoto et al., 2006; Sasaki et al., 2007, 2016).

In this study, 13 sample plots (restoration plots) within Expo Park were investigated (Fig. 1b). Among them, ten plots (E1-E10) were already established and investigated in the previous studies (Morimoto and Kobashi, 1985; Njoroge and Morimoto, 2000; Sasaki et al., 2007). For these plots, the earliest complete surveys used in this study were conducted in 1995. To increase the number of survey plots, we established three new plots (E11–E13) in 2006. The plot sizes ranged from 150 m^2 (10 m × 15 m) to 375 m^2 (15 m × 25 m) depending on tree size and density of the stands (Table 1). The first survey for this study was conducted in 2004 (E1–10) and 2006 (E11–13) when we labeled all trees greater than 1 cm in diameter at breast height (DBH, 1.3 m above ground level), and measured the DBH and tree height (H). In 2008, we re-measured the DBH and H of all labeled trees, and recorded new individuals greater than 1 cm in DBH. We conducted a third measurement of DBH and H in 2014, and measured all new individuals taller than 1.3 m regardless of DBH.

As the reference forest, we selected a mature, late-successional forest at Taisanji Temple (34°41′N, 135°04′E, 70–200 m ASL, Fig. 1a), Hyogo Prefecture, Japan, 43 km west of the Expo Park. This forest is dominated by *C. cuspidata*. The oldest tree is ca.95 years and the forest is estimated to be more than 100 years old (Azuma et al., 2014). This forest has been used as a place of Buddhist religious training and has had minimal human intervention, resulting in a highly natural forest with high species richness, representative of mature, late-successional forest in this region (Ishida et al., 1998). Thus, this forest could be considered as a reference vegetation that was intended for the forest restoration in the Expo '70 Park. Although using more than one reference sites is desirable (Ruiz-Jaén and Aide, 2005a), there were no other late-successional forests within a reasonable distance of Expo '70 Park, because in the warm-temperate zone in Japan, vegetation has been strongly affected by human intervention, and very few natural forests remain (Kamada, 2005). In 2008, we measured DBH of all trees taller than 1.3 m in four 10 × 20 m plots (T1–T4, reference plots: Fig. 1b, Table 1), followed by a re-measurement of DBH and measurement of H in 2014. These data were compared with data from the first survey conducted in 2003 by Azuma et al. (2014). In all study plots, H was measured by a telescoping pole for trees shorter than 12 m and by an ultra-sound clinometer (Vertex III, Haglof, Sweden) for taller trees.

2.2. Data analysis

In this study, *C. sieboldii* and *C. cuspidata* were grouped together because these two species are genetically similar, known to hybridize, and difficult to distinguish morphologically (Yamada and Nishimura, 2000).