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Twenty-one years of stand dynamics in a 33-year-old urban forest restoration site at Kobe Municipal Sports Park, Japan

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ABSTRACT

To integrate human-disturbed hillslopes with the regional landscape, natural forest restoration has become an important objective of hillslope re-vegetation in Japan. At Kobe Municipal Sports Park (KMSP), seedlings of native species were planted in 1980 to restore semi-natural secondary forest (*satoyama*) in an urban setting. Here, we present 21 years of stand dynamics based on vegetation surveys conducted in 1992, 2000, and 2013 in two research plots (control and managed) at KMSP in relation to a reference forest to evaluate management effects and restoration success. Total basal area continued to increase in both the plots, but diameter-growth decreased in the control plot, whereas it continued to increase in the managed plot, which had been thinned by volunteers. In the control plot, which was planted at higher initial density than the managed plot, *Quercus phillyraeoides* (evergreen, mid-canopy tree) dominated the single-layered canopy and vertical development was delayed. In the managed plot, *Quercus serrata* (deciduous, canopy tree) dominated the upper canopy layer and evergreen broadleaved trees dominated the mid- to lower-canopy layers, resulting in a vertically well-developed canopy similar to the reference forest. The basal area of *Robinia pseudoacacia* decreased due to shading by evergreen trees, whereas that of *Nerium oleander*, an exotic species, had increased in the control plot. Ordination results indicated that vegetation of the control plot was diverging away from the reference forest, whereas thinning had directed the managed plot toward it. Our results confirm that simultaneously planting seedlings of native species does not lead to natural forest stand structure. In the future, adaptive management, such as periodic thinning, removal of shade-tolerant, exotic species and enrichment planting of native species, will be needed to integrate forest restoration sites with the surrounding mid-successional, secondary forest.

Introduction

Because Japan is a mountainous country, the main objective of re-vegetation on natural and man-made slopes is to increase plant cover quickly to stabilize the soil and prevent erosion (Yoshida, 2007; Zuazo and Pleguezuelo, 2008). Recently, natural forest restoration has also become an important objective to realize integration of human-disturbed slopes with the regional landscape. Various methods have been proposed that use native seedlings and juvenile trees, which are planted simultaneously in an effort to restore natural forest vegetation (e.g., Miyawaki, 2004; Morimoto et al., 2006; Yamagawa et al., 2010; Yoshida, 2007). It is uncertain, however, whether such efforts will actually produce mature, native forests (Oldfield et al., 2013). Most studies monitoring the development of natural forest restoration projects report progress within ≤5 years after planting (Oldfield et al., 2013, their Table 1). In addition, due to logistic and budgetary constraints, most reforested sites remain unmanaged and subsequent adaptive management to direct succession toward native forest composition and structure is rarely conducted (but see, MacKay et al., 2011). Thus, there is a need to accumulate case studies to compare and evaluate the long-term outcome of various restoration projects and to assess the need for adaptive management (Ruiz-Jaén and Aide, 2006).

We are aware of only one study of forest restoration in Japan spanning more than 30 years in Expo Park in Osaka, where seedlings of late-successional species were planted in the 1970s to restore the native, warm-temperate evergreen-broadleaved forest. Thirty years later, the stand had become dense with a single-layered canopy dominated by late-successional, evergreen trees, and lower-canopy and understory species composition was poor

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(Nakamura et al., 2005). Thinning and gap-formation experiments were conducted to increase seedling regeneration in the understory and create vertically well-developed canopies that more closely resemble the structure and function of natural forests. The results of the EXPO Park reforestation project suggest that simultaneously planting seedlings of late-successional species does not lead to stand structures resembling natural forests and that adaptive management may be needed to direct succession of forest restoration sites toward natural forest composition and structure (Rebele and Lehman, 2002; Robinson and Handel, 2000; Tojima et al., 2004).

Recently, multiple criteria, including species diversity, vegetation structure, and ecosystem processes are used to evaluate restoration success (Ruiz-Jaén and Aide, 2005a). Vegetation structure is an important measure for predicting the future direction of succession after forest restoration, because structural complexity facilitates colonization by plant species other than those that were planted (Ruiz-Jaén and Aide, 2006). Vegetation structure is also correlated with diversity of other organisms (insects, birds, amphibians, etc.) and various ecosystem processes, such as seed dispersal and nutrient availability (Gamfeldt et al., 2013; Ishii et al., 2004; Ruiz-Jaén and Aide, 2005b). When promoting colonization after forest restoration, however, care must also be taken to prevent invasion of restoration sites by exotic species and escaped ornamentals (Ishii and Iwasaki, 2008; Sullivan et al., 2009).

Here, we report 21 years (1992–2013) of vegetation dynamics in a 33-year-old urban forest restoration site in Kobe Municipal Sports Park, Kobe City, Japan (hereafter KMSP). This site is different from EXPO Park because part of the forest was intensively managed by civilian volunteers in an effort to recreate the structure and function of semi-natural secondary forests of rural Japan (*satoyama*), which was the dominant landscape before construction of KMSP. In recent years, agricultural use of *satoyama* has ceased and many abandoned secondary forests are maturing and succeeding toward late-successional evergreen broadleaved forest (Azuma et al., 2014; Takeuchi et al., 2003; Yokohari and Amati, 2005) and forests surrounding KMSP have similar land-use history. When the surrounding vegetation is in mid-succession, integration of forest restoration sites with the regional landscape becomes more difficult, because the restoration effort must pursue a "moving target" (Hotta and Ishii, 2015). At KMSP, we analyzed the long-term vegetation dynamics following forest restoration using data from three vegetation surveys spanning 21 years. We compare composition and structure between control (unmanaged) and managed plots relative to a reference, semi-natural secondary forest to evaluate the success of adaptive management at this forest restoration site.

Materials and methods

Study site

KMSP is located in Suma Ward, Kobe City, Hyogo Prefecture in southwestern Japan (34.68° N, 135.07° E, 100 m ASL, Fig. 1a). The inherent natural vegetation of this region is warm-temperate evergreen broadleaved forest (Miyawaki et al., 1984). Before KMSP was established, the area was semi-natural secondary forest (*satoyama*), abandoned for ca. 30 years after being intensively managed for firewood and organic soil to be used for agriculture. In 1980, after construction of KMSP, man-made cut slopes within the park were re-vegetated after adding more than 30 cm of topsoil. To restore the semi-natural secondary forest, saplings of native tree species, such as *Quercus serrata* Murray (deciduous), *Quercus glauca* Thunb., and *Quercus phillyraeoides* A. Gray (evergreen), were planted (Yoshida et al., 2002).

In 1992, two research plots, control (unmanaged) and managed, were established on a north-facing slope (mean inclination = 25.0°) to investigate vegetation change after restoration (Fig. 1b; Doi et al., 1993). The diameter at breast height (DBH, 1.3 m above ground level) and height of all woody plants taller than 1.3 m was measured in both the plots. Quantitative data on the number and species of trees planted in the plots were not available. Based on the total number of live and dead trees in the plots in 1992, Doi et al. (1993) estimated that the initial planting densities were ca. 0.64 and 0.22 trees per m^2 in the control and managed plots, respectively. In 2002, a second survey was conducted (Yoshida et al., 2002), followed by a third survey in 2013. We interviewed former volunteers and park employees and found that the understory of the study area including the managed plot was thinned during 2006–2007 and that *Nerium oleander* L., an exotic species, was removed from the area between the managed and control plots in 2010. Quantitative data of the management practices, however, were not recorded.

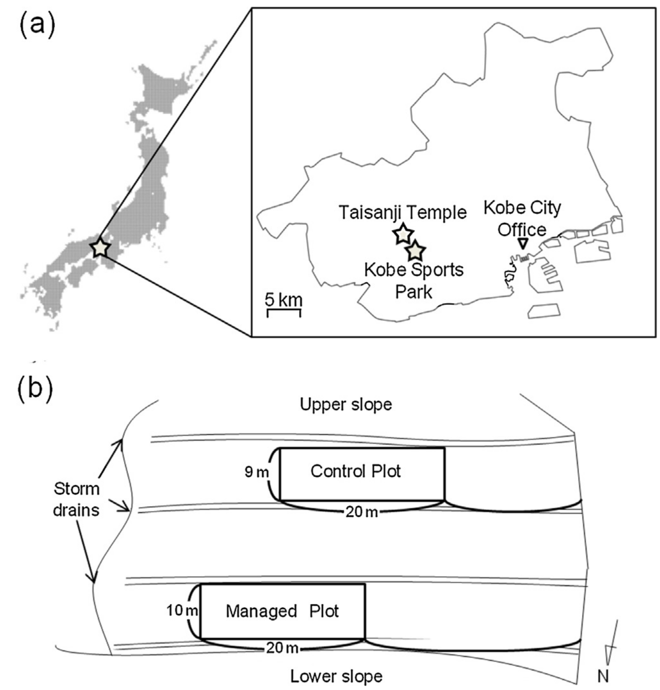

Fig. 1. Location of the study sites, Kobe Municipal Sports Park (restoration site) and Taisanji Temple (reference forest) within Kobe City, Japan (a) and the layout of the control and managed plots in the restoration site (b).

Data analysis

Because our plots were not replicated, statistical tests could not be conducted. To evaluate restoration success, we compared the species composition of the restoration site with that of the reference forest using subjective Bray Curtis ordination analysis (Beals, 1984) in R (vegan package, ver. 2.14.1, R Development Core Team). In this method, vegetation data of the restoration site are plotted in relation to selected reference points. The position and distance of the restoration site relative to the reference vegetation and the direction of change over time can be interpreted as restoration success (Ruiz-Jaén and Aide, 2006). As the reference forest, we selected the mature semi-natural secondary forest at Taisanji Temple (34.68 N, 135.07° E, 70–200 m ASL, Fig. 1a), 2 km from the study site, where a vegetation survey was conducted in six 10 × 20 m plots 2008 (Azuma et al., 2014). The land-use history of the reference forest is similar to that of the forests that existed before construction of KMSP, i.e., a secondary forest that was intensively used as *satoyama* until the 1950s, then abandoned (Iwasaki and Ishii 2005). Thus, this forest could be considered as the reference vegetation that was intended for the forest restoration project at KMSP.