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Vegetation recovery after removal of invasive *Trachycarpus fortunei* in a fragmented urban shrine forest

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ABSTRACT

To evaluate the effectiveness of active management on ecological restoration of urban forest fragments, we investigated recovery of the native vegetation in an urban shrine forest in central Japan after complete removal of the invasive warm-temperate palm, *Trachycarpus fortunei* Wendl. Nine years after removal, stand density and basal area of the remaining tree species had recovered to pre-removal values. Number and basal area of native evergreen trees, such as *Cinnamomum japonicum* Sieb. and *Ficus erectus* Thunb., had increased, especially in the lowest canopy layer where *T. fortunei* had dominated. As a result, species composition of the shrub layer shifted from dominance by single invasive species (*T. fortunei*) to multiple native species. However, exotic species and escaped ornamentals, such as *Lingustrum lucidum* Ait. and *Euronymus japonicus* Thunb., had also increased, especially in the forest edge. Our results indicate that removal of invasive species contributes to recovery of native vegetation. However, to maintain near-natural conditions considered ideal for shrine forests, continuous monitoring and management will be needed to prevent invasion by exotic and ornamental species.

Introduction

In densely populated urban areas of Japan, where development of new green space is restricted, forests associated with shrines and temples are recognized as important components of urban green space, which can potentially function as centers for ecosystem conservation (Ishii et al., 2010). They represent isolated patches of vegetation protected for purposes of religious worship in an increasingly human-dominated landscape, similar to religious green space, such as cemeteries and churchyards of other cultures (Bell et al., 2007; Ignatieva et al., 2010). In urban areas of Japan, shrines tend to be spatially scattered across the landscape but associated with specific geographical features, such as small hills, rocky outcrops, spring water, and streams, which are objects of nature worship (Fujita and Kumagai, 2007). Their widespread distribution suggests that shrine forests can potentially be used as stepping stones in the urban green space network (Ishii et al., 2010). In addition, shrine forests have social value, providing aesthetic and environmental pleasure to visitors (Fujita and Kumagai, 2007; Imanishi et al., 2007; Manabe et al., 2007).

Some shrine forests have been protected in near-natural conditions for centuries and comprise the native vegetation of the region (Manabe et al., 2003; Imanishi et al., 2007; Ishii et al., 2010), but most have experienced various degrees of anthropogenic disturbances (Hattori et al., 2003; Tabata et al., 2004) while some, like Meiji Shrine in central Tokyo (Torikai, 2003), were artificially created to mimic the natural vegetation. Traditionally, shrine forests have been maintained with minimum vegetation management because it was believed that near-natural conditions desirable for shrine forests could be conserved by minimizing human intervention (Hashimoto et al., 2008). However, several studies have shown that in urban areas, lack of management has resulted in invasion of the forest by exotic and ornamental species creating undesirable conditions (Manabe et al., 2007; Ishii and Iwasaki, 2008). Active management, such as removal of invasive species and enrichment planting of native species, may be needed to restore near-natural forest conditions considered ideal for shrine forests as icons of nature worship (Ishii and Iwasaki, 2008; Snep and Opdam, 2010).

Here, we report results of a forest restoration project in an urban shrine forest (Nishinomiya Shrine) in central Japan, where *Trachycarpus fortunei* Wendl., an escaped ornamental species, was completely removed from the forest as part of active vegetation management. *T. fortunei* is an extremely shade tolerant, monocot species of subtropical origin whose seeds are bird dispersed. It has been found to spread rapidly in the understory of urban forests preventing regeneration of native species (Hagiwara, 1979; Koike, 2006). Before the restoration project, large leaves of *T. fortunei* covered the understory of the shrine forest at Nishinomiya Shrine

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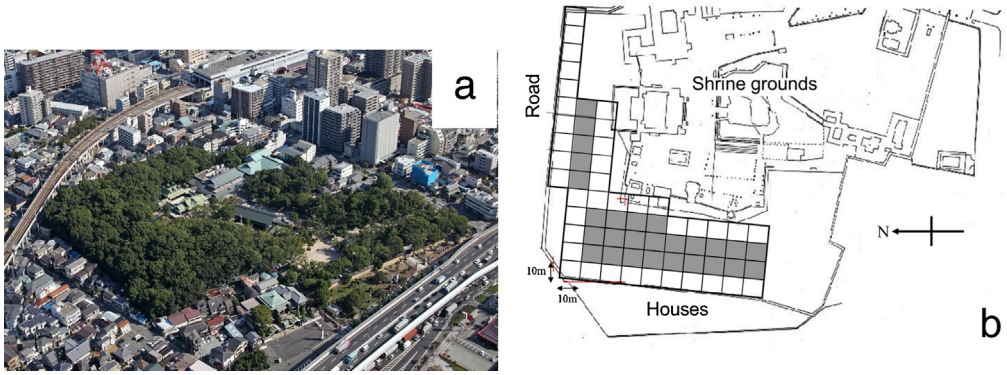

Fig. 1. Aerial view (a) and map (b) of Nishinomiya Shrine in southeastern Hyogo Prefecture, Japan. The evergreen broadleaved forest is located on the north and west sides of the shrine grounds. A 0.65 ha contiguous research plot was established comprising 65 $10 \times 10\,m^2$ sub-plots, which were designated as edge (open) and interior (filled) environments.

(Ishii and Iwasaki, 2008). In this paper, we report changes in species composition and stand structure of the shrine forest three and nine years after removal of *T. fortunei* and infer the rate of vegetation recovery. To our knowledge, this study represents the first example of forest restoration and active, long-term vegetation management in an urban shrine forest in Japan.

Materials and methods

Study site

The study was conducted at Nishinomiya Shrine in Nishinomiya City, southeastern Hyogo Prefecture, Japan (34°43′N, 135°20′E, 2 m asl). Mean annual temperature and precipitation are 17.0 °C and 1468 mm (2005–2014). The 4.2 ha shrine area is located in a highly urbanized landscape including roads, railroad, houses, and buildings (Fig. 1a). The forest is an evergreen broadleaved forest dominated by large, planted trees of *Cinnamomum camphora* Sieb. Other dominant species include, native evergreen trees such as *Ilex rotunda* Tunb., *Quercus glauca* Thunb., *Camellia japonica* L., and *Cinnamomum japonicum* Sieb. (Table 1).

The forest was designed to represent the indigenous natural vegetation of the region, which is warm-temperate evergreen broadleaved forest (Miyawaki et al., 1984), and to create the ambiance for Shinto's nature worship. Old photos of the shrine grounds suggest the dominant *C. camphora* trees were planted about 100 years ago. Before that, old illustrations of the forest suggest that pine trees dominated the forest. In 1961, the Hyogo Prefectural Government designated 1.3 ha of the forested area on the north and west side of the shrine grounds as a cultural heritage site representing late successional forest vegetation of the region. However, a vegetation survey conducted in 2003 showed that the understory was dominated by *T. fortunei*, an invasive palm (Iwasaki and Ishii, 2005). Iwasaki and Ishii (2005) found that *T. fortunei* contributed 23.2% (649 trees ha^{-1}) of the total number of trees in the shrine forest. With permission from the shrine and Prefectural Government, all individuals of *T. fortunei* were removed in the winter of 2005 in an effort to restore near-natural forest conditions. Tall individuals were cut down using a brush cutter equipped with a rotating steel blade, while small individuals were pulled from the ground by hand. This amounted to 3.4% and 27.9% of the total basal area and leaf area, respectively of the stand (Ishii and Iwasaki, 2008). In each subsequent year, newly recruited seedlings of *T. fortunei* were removed by hand.

Field measurements and statistical analyses

In 2003, we established a 0.65 ha contiguous research plot within the forest (Fig. 1b). Each $10 \times 10\,m^2$ sub-plot was designated as edge (within 10 m of the forest edge) or interior (more than 10 m from the forest edge) environment. We identified all

Table 1
Species composition of the evergreen broadleaved forest at Nishinomiya Shrine in southeastern Hyogo Prefecture, Japan.

	Number of trees (ha^{-1})						Basal area (m^2/ha)					
Species	2003		2008		2014		2003		2008		2014	
Trachycarpus fortunei^{inv}	645	(23.0)	–	–	–	–	1.65	(3.3)	–	–	–	–
Camellia japonica	451	(16.1)	462	(20.1)	419	(15.2)–	0.70	(1.4)	0.78	(1.5)	0.79	(1.5)
Cinnamomum japonicum	245	(8.7)	274	(11.9)	399	(14.4)+	0.67	(1.3)	0.77	(1.5)	0.90	(1.7)
Ilex rotunda	214	(7.6)	212	(9.3)	226	(8.2)	2.15	(4.3)	2.41	(4.7)	2.57	(4.8)
Quercus glauca*	172	(6.2)	181	(7.9)	206	(7.5)	1.21	(2.4)	1.18	(2.3)	1.35	(2.5)
Aphanathe aspera*	172	(6.2)	173	(7.5)	164	(5.9)	4.54	(9.1)	4.73	(9.3)	4.67	(8.7)
Cinnamomum camphora*	165	(5.9)	163	(7.1)	161	(5.8)	33.24	(66.5)	34.95	(68.5)	36.52	(68.3)
Ficus erectus	143	(5.1)	175	(7.6)	224	(8.1)+	0.04	(0.1)	0.06	(0.1)	0.09	(0.2)
Ligustrum japonicum	94	(3.4)	92	(4.0)	84	(3.0)	0.24	(0.5)	0.28	(0.6)	0.32	(0.6)
Ligustrum lucidum^{*ex}	94	(3.4)	129	(5.6)	200	(7.2)+	0.23	(0.5)	0.31	(0.6)	0.45	(0.8)
Ternstroemia gymnanther	92	(3.3)	95	(4.2)	98	(3.5)	0.46	(0.9)	0.49	(1.0)	0.51	(1.0)
Aucuba japonica	72	(2.6)	74	(3.2)	99	(3.6)	0.01	(0.0)	0.02	(0.0)	0.02	(0.0)
Euronymus japonicus^{*orn}	48	(1.7)	70	(3.1)	244	(8.8)+	0.03	(0.1)	0.04	(0.1)	0.13	(0.2)
Others	191	(6.8)	192	(8.4)	240	(8.7)	4.92	(9.8)	4.90	(9.6)	5.16	(9.7)
Total	2797	(100.0)	2293	(100.0)	2764	(100.0)+	50.09	(100.2)	50.90	(99.8)	53.49	(100.0)

Species are listed in order of decreasing number in 2003. Figures in parentheses indicate percent of total. Names of deciduous species are indicated in bold. Asterisks indicate shade intolerant species. *T. fortunei* is invasive (inv), *L. lucidum* is exotic (ex) and *E. japonicus* is ornamental (orn). Plus (+) or minus (–) signs next to values indicate significant increase or decrease, respectively, of each species (ANOVA, $P < 0.05$).