Report

Microclimate mitigation in shrine/temple forests of southeastern Hyogo Prefecture

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Abstract

Microclimate mitigation was compared among three shrine/temple forests with different vegetation and surrounding landscapes: Kiyoshi Kojin Temple (native lucidophyllous forest surrounded by mountainous conifer plantations and secondary forest), Taisanji Temple (native lucidophyllous forest surrounded by suburban farm fields and rice paddies) and Nishinomiya Ebisu Shrine (artificial laurel forest surrounded by urban roads and buildings). Automatic temperature/humidity sensors were placed in the forest exterior and interior. Monthly mean temperature was generally higher and humidity lower at the forest exterior than in the interior. In August, mid-day temperature difference between exterior and interior were greater at Nishinomiya (4.4°C) than at Taisanji (3.1°C) and Kiyoshi Kojin (2.8°C). At Nishinomiya, the exterior temperature was higher than the interior even during the night, whereas, at Kiyoshi Kojin and Taisanji, exterior night-time temperature was similar to or lower than the interior. With the decline in temperature, relative humidity generally increased each night. However, at Nishinomiya, there were periods during the summer when night-time relative humidity remained low, even in the forest interior. The difference in microclimate between the forest exterior and interior was most marked at Nishinomiya, followed by Taisanji and Kiyoshi Kojin. These results illustrated the importance of native lucidophyllous forests in maintaining forest-interior conditions in suburban areas and of evergreen shrine/temple forests in mitigating microclimates in urban areas.

Key words: conservation, forest fragmentation, lucidophyllous forest, urban forest

Introduction

In Japan, shrine/temple forests represent remnant pieces of what used to be continuous forest cover fragmented by increasing human-dominance of the landscape. These fragmented forest islands have been protected for purposes of religious worship and may be several decades to hundreds of years old. Those comprising natural forest are sources of basic ecological information on the original landscapes and native vegetation of the region, as well as important refugia for many endangered species. The fragmented nature of shrine/temple forests raises several questions regarding their conservation. What is the relationship between forest area and species diversity? What is the minimal area needed to sustain biological diversity of native species? What is the mechanism by which forest fragments sustain biological diversity? Several studies have found that species diversity increases as the area of the forest fragment increases (e.g., Maesako, 1987; Maesako, 1990; Ishida et al., 1998; Hattori and Ishida, 2000). In their comparative study of the species-area relationship of shrine/temple forests in southeast Hyogo Prefecture, Ishida et al. (1998) estimated that as much as 1500 ha may be needed to conserve all native flora. As it is realistically impossible to set aside such a large area for conservation, we must strive to conserve several small areas comprising various types of vegetation. In designating such small conservation areas, we must take into account the influence of the surrounding landscape, i.e., edge effects (Murcia, 1995).

As forests become more fragmented, the area occupied by edge environments increases (Young and Mitchell, 1994). The increasing proportion of edge environments promotes the influx of non-forest species from the surrounding landscape (Brothers and Spingarn, 1992; Maesako, 2000; Cadenasso and Pickett, 2001; Meiners et al., 2002). Maesako (2000) found that species with bird-dispersed seeds dominated regeneration in the understory of a fragmented secondary forest in western Japan. In addition, the forest edge is a harsh environment for many late-seral species that prefer the moist, shady environment of the forest interior (Ranny et al., 1981; Saunders et al., 1991; Matlack, 1994; Ozanne et al., 1997). Thus, early-seral, light-loving species dominate near the forest edge. This may be detrimental for the conservation of late-seral species if only small areas mostly consisting of edge environments can be set aside.

The extent to which forest cover mitigates the harsh environment of the surrounding human-dominated landscape and forest-edge environments may depend on the vegetation type and structure of the forest edge as well as the nature of the surrounding landscape (Cadenasso and Pickett, 2001). Although there are several ecological studies of shrine/temple forests (e.g., Sakamoto et al., 1985; Kodate et al., 1997; Manabe et al., 2003), most are studies of the vegetation structure of a single forest. Only a limited number of studies have compared shrine/temple forests of different vegetation types and settings (Sakamoto et al., 1989; Sakamoto et al., 1993). Similarly, intensive, short-term studies that compared the microclimate at the forest edge and the interior of a single location have been conducted (e.g., Takeda et al., 1978; Takeda et al., 1979). However, we are aware of no previous published work that compared microclimate mitigation among shrine/temple forests with different vegetation and surrounding landscapes over the course of an entire growing season.

In this paper, we compare the degree of microclimate mitigation among different types of fragmented shrine/temple forests. We chose three forest types with different surrounding landscapes as our research sites (Table 1). These three study sites, with their variety of sizes and types of forest cover in combination with different surrounding landscapes, represent many other shrine/temple

Table 1. Description of the study sites.

Study site	Kiyoshi Kojin	Taisanji	Nishinomiya
Forest type	Native lucidophyllous	Native lucidophyllous	Artificial laurel
Surrounding landscape	Mountainous landscape: secondary forest *Cryptomeria*plantation	Rural landscape: rice paddies farm fields	Urban landscape: buildings, roads, railroad, highway
Canopy dominant	*Castanopsis cuspidata*	*Castanopsis cuspidata*	*Cinnamomum camphora*
Other tree spp. (in order of basal area)	*Quercus glauca* *Camelia japonica* *Ilex rotunda* *Ilex pedunculosa*	*Ilex integra* *Camelia japonica* *Quercus glauca* *Ilex rotunda*	*Cinnamomum japonicum* *Ilex rotunda* *Celtis sinensis* *Aphananthe aspera*
Canopy openness	Exterior: 32.5% Interior: 8.3%	Exterior: 36.1% Interior: 8.2%	Exterior: 40.0% Interior: 9.1%

forests typically found throughout Japan. From our results, we infer the degree to which each forest is able to mitigate the harsh environment of the forest exterior and maintain the stable environment of the forest interior.

Methods and Study Sites

Automatic temperature/humidity sensors (Thermoleaf Plus, Taisei E&L Corp.) were placed one each in the forest interior and exterior, respectively. Each sensor was placed inside an aluminium-covered housing with an open bottom and hung 1 m above ground level on a plastic pole. Temperature and relative humidity readings were logged at 30-minute intervals from May to December 2003. From a previous survey using hemispherical photography, we determined that, at each site, light conditions of the forest interior stabilized at more than 30 m from the forest edge (Ishii et al., 2004). Therefore, the interior sensors at each site were placed more than 30 m from the forest edge. The exterior sensor was placed in an exposed area just outside of the forest that was representative of the surrounding landscape. See detailed explanation for each study site below.

Kiyoshi Kojin Seichoji

The native lucidophyllous forest at Kiyoshi Kojin Temple in Takarazuka City (34°47'N, 135°21'E, 100-160 m ASL) is a 1.6-ha forested area surrounded by a mountainous landscape with secondary forests and *Cryptomeria japonica* D.Don plantations. The canopy is dominated by *Castanopsis cuspidata Schottky* var. sieboldii Nakai. The lower canopy is dominated by *Camelia japonica* L. and *Quercus glauca* Thunb. The research site is on a steep slope facing the southeast. At this site, the interior sensor was placed at 44 m from the forest edge, while the exterior sensor was placed in an exposed area among the temple buildings. Light conditions at each sensor location were determined using hemispherical photographs. Canopy openness was 36.1% and 8.2% for the forest exterior and interior, respectively.

Taisanji

The lucidophyllous native forest at Taisanji Temple in the suburbs of Kobe City (34°41'N, 135°40'E, 70-200 m ASL) is a 16-ha forested area surrounded by a suburban landscape with rice paddies and farm fields. The canopy is dominated by *Castanopsis cuspidata* and *Ilex rotunda*. The lower canopy is dominated by *Camelia japonica* and *Q. glauca*. The lucidophyllous forest is considered a remnant of the native vegetation of the region (Kodate et al., 1997). The research site is on a gentle slope facing the southwest. At this site, the interior temperature sensor was placed at 37 m from the forest edge while the exterior sensor was placed in a rice field just outside of the forest edge. Canopy openness was 32.5% and 8.3% for the forest exterior and interior, respectively.

Nishinomiya Ebisu

The artificial laurel forest at Nishinomiya Ebisu Shrine in Nishinomiya City (34°43'N, 135°20'E, 2 m ASL) is a 4.2-ha area surrounded by an urban landscape with roads and houses. The shrine is designated as a cultural heritage site by Hyogo Prefecture. The canopy is dominated by large planted trees of *Cinnamomum camphora* averaging ca. 1 m in diameter at breast height and ca. 20 m in height. Other canopy trees include *I. rotunda, Celtis sinensis* Pers. var. *japonica* Nakai and *Aphananthe aspera* Planch. Lower-canopy species include *Q. serrata*, *Camelia japonica* and *Cinnamomum japonicum* Sieb. The topography of the research site is very flat. At this site, the interior sensor was placed 35 m from the forest edge, while the exterior sensor was placed in a parking lot outside of the concrete wall that surrounded the shrine forest. Canopy openness was 40.0% and 9.1% for the forest exterior and interior, respectively.

Results

Seasonal variation

Monthly mean temperatures were lowest at Kiyoshi Kojin and highest at Nishinomiya Ebisu (Fig.1). Within each site, the monthly mean temperature of the forest exterior was higher than that of the forest interior except at Taisanji during October through December. The greatest difference between the forest exterior and interior was observed at Nishinomiya Ebisu in September, where the mean exterior temperature was 1.6°C higher than the interior. Within each site, the monthly maximum temperature of the forest exterior was higher than that of the interior except during December. The

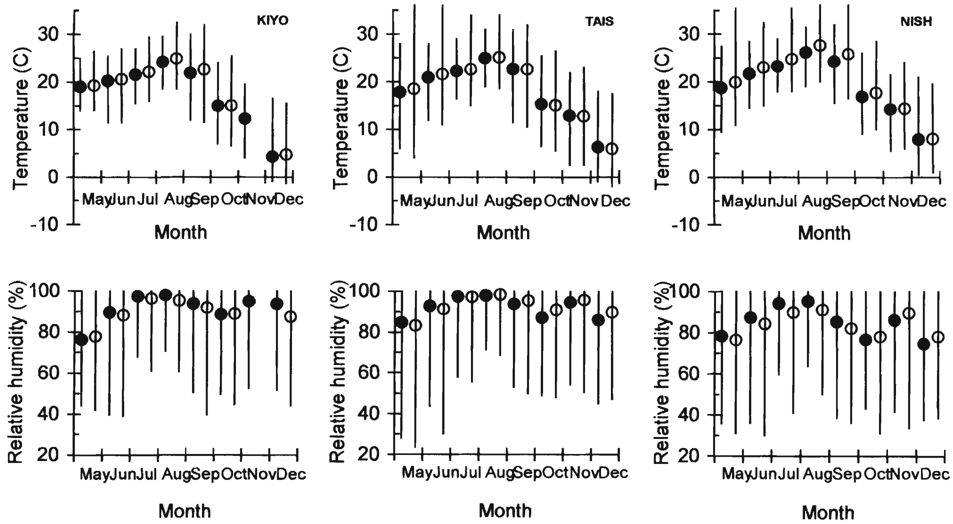

Fig. 1. Monthly mean temperature and relative humidity of the forest interior (filled symbols) and exterior (open symbols) at the shrine/temple forest sites in southeastern Hyogo Prefecture. Bars indicate monthly maximum and minimum values. Data for the forest exterior at Kiyoshi Kojin in November is missing due to sensor malfunction.

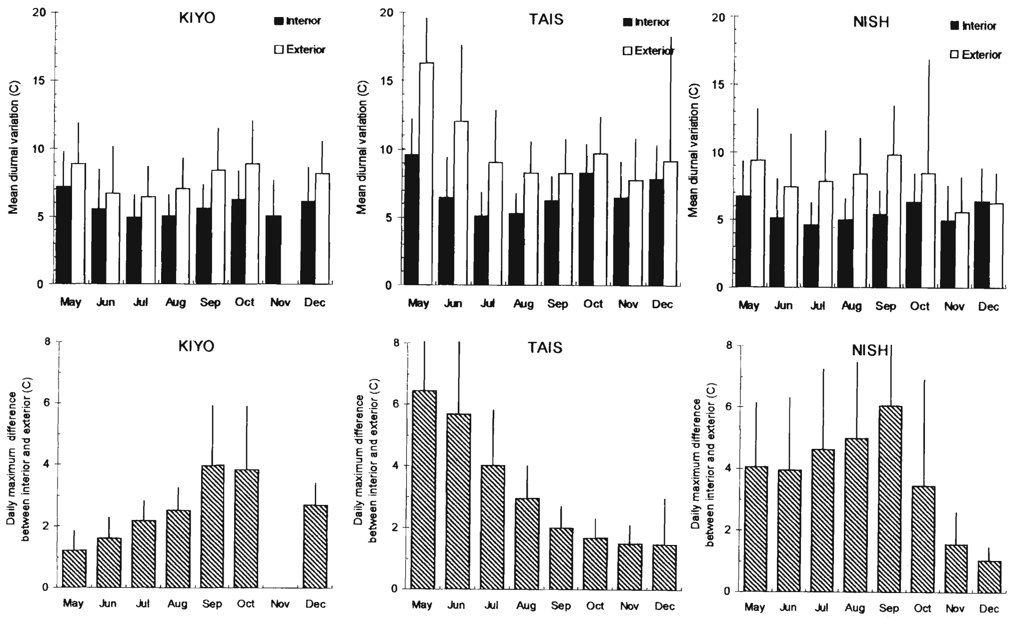

Fig. 2. Mean diurnal variation (difference between daily maximum and minimum temperature) for the forest interior (filled bars) and exterior (open bars) along with daily maximum difference in temperature between the forest interior and exterior at the shrine/temple forest sites in southeastern Hyogo Prefecture. Error bars indicate one standard deviation.

highest exterior temperature (38.5°C on August 4) and highest interior temperature (32.0°C on September 9) both occurred at Nishinomiya Ebisu. The monthly minimum temperature of the forest exterior was lower than that of the forest interior at Kiyoshi Kojin and Taisanji. In contrast, the monthly minimum temperature of the forest exterior was higher than that of the interior at Nishinomiya Ebisu.

Monthly mean values for relative humidity were generally lower at Nishinomiya Ebisu than at the other two sites. Within each site, the monthly mean humidity of the forest exterior was generally lower than that of the interior during spring (May-Jun) and summer (Jul-Sep). However, this relationship tended to be reversed during autumn and winter (Oct-Dec). The greatest difference between the exterior and interior was observed in July at Nishinomiya Ebisu, where the mean exterior humidity was 4.3% lower than the interior. The monthly maximum humidity was always 100% due to the nature of the sensor which tends to overestimate relative humidity when temperatures drop quickly. The monthly minimum humidity of the forest exterior was generally lower than that of the interior. The lowest exterior humidity (31% on May 9 and October 29) and lowest interior humidity (35.5% on May 21) both occurred at Nishinomiya Ebisu.

Diurnal variation

Diurnal variation in temperature (the difference between daily maximum and minimum temperature) was greatest at Taisanji, averaging as much as 16.3°C at the forest exterior and 9.6°C in the forest interior during May (Fig. 2). At all sites, diurnal variation was greater during spring and autumn months than in summer and winter. Diurnal variation of the forest exterior was greater than that of the interior except at Nishinomiya Ebisu during December. The daily maximum difference in temperature between the forest exterior and interior was greatest at Nishinomiya Ebisu, averaging as much as 4.0 to 6.1°C during May through September. Daily maximum difference was also large at Taisanji, averaging 6.4 to 4.0°C during May through July. At Kiyoshi Kojin and Nishinomiya, the daily maximum difference was greatest during September, whereas at Taisanji it was greatest during May.

Mean diurnal pattern on clear days in August indicated that temperatures began to increase at 6:00 to 7:00 (Fig. 3). At Kiyoshi Kojin, the night-time temperatures of the forest exterior and interior were similar. After 8:00, the exterior temperature increased more rapidly than the interior. The greatest difference (2.8°C) between the forest exterior and interior occurred at 13:00. In the afternoon, exterior temperature decreased more rapidly than the interior to reach similar values after 19:00. At Taisanji, the night-time temperature of the forest exterior was lower than that of the interior. However, in the early morning, the exterior temperature increased more rapidly than the interior. After 8:30, the exterior temperature was higher than the interior. The greatest difference (3.1°C) between the forest exterior and interior occurred at 13:30 and 14:00. In the afternoon, the exterior temperature decreased more rapidly than the interior. After 18:00, the exterior temperature was lower than the interior. At Nishinomiya Ebisu, the night-time temperature of the forest exterior was higher than that of the interior. This difference became more marked during the day. The greatest difference (4.4°C) between the

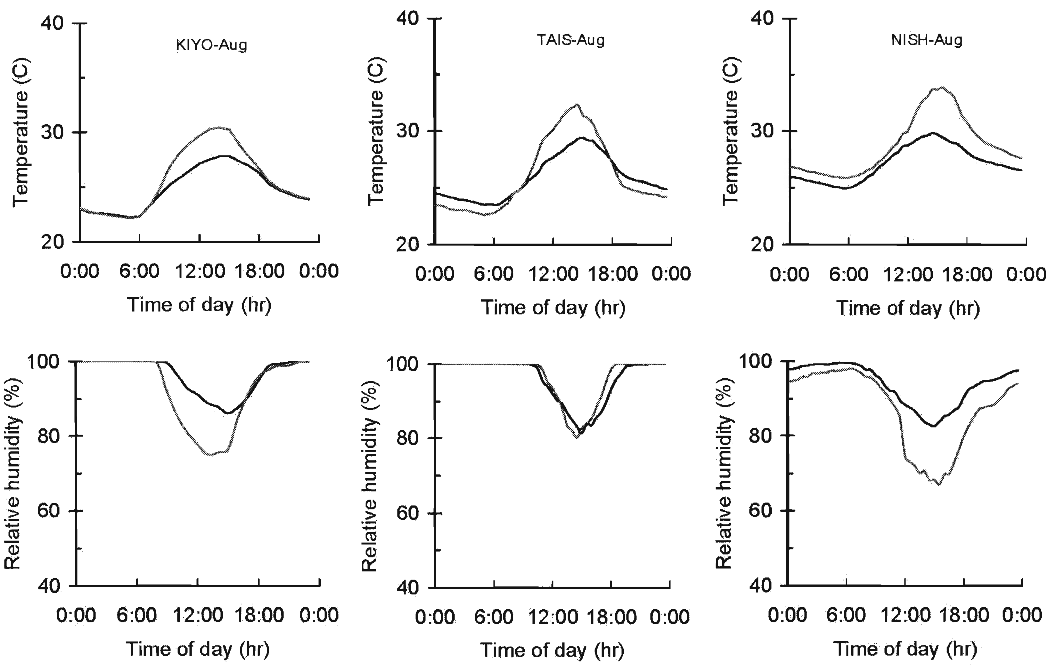

Fig. 3. Mean diurnal pattern of temperature and relative humidity of the forest exterior (gray line) and interior (black line) on clear days in August at the shrine/temple forest sites in southeastern Hyogo Prefecture.

forest exterior and interior occurred at 15:30, after which the exterior temperature decreased, but remained higher than the interior even during the night.

Diurnal changes in relative humidity on clear days in August corresponded to those of temperature. The relative humidity of the forest exterior decreased more rapidly than that of the interior during the morning, and differences in relative humidity between the forest exterior and interior were greatest during the day. The greatest difference in humidity between the forest exterior and interior was observed at Nishinomiya Ebisu (13.1% at 12:30). At Kiyoshi Kojin and Taisanji, night-time humidity recovered to 100% in both the forest exterior and interior. This resulted from the tendency of the ThermoLeaf sensors to overestimate relative humidity when temperatures drop quickly. Despite this tendency, night-time humidity did not recover to 100% at Nishinomiya Ebisu, and the relative humidity of the forest exterior was lower than that of the interior even during the night.

The mean diurnal pattern on clear days in December indicated that temperatures began to increase at 8:00 to 8:30 (Fig. 4). At Kiyoshi Kojin, the night-time temperature of the forest exterior was slightly higher than that of the interior from 1:00 to 9:00. After 9:00, the exterior temperature increased more rapidly than the interior. The greatest difference (2.6˚C) between the forest exterior and interior occurred at 14:00. The exterior temperature was lower than that of the forest interior from 18:00 to 1:00. At Taisanji, the night-time temperature of the forest exterior was lower than that of the interior. The exterior temperature was not more than 1˚C higher than that of the interior during the day (9:30 to 16:00). At Nishinomiya Ebisu, the night-time temperature of the forest exterior was slightly (< 1˚C) higher than that of the interior. From 8:30 to 12:30, the exterior temperature was slightly lower than the interior. After 12:30, the exterior temperature was slightly higher than the interior.

Diurnal changes in relative humidity on clear days in December were more variable than those of temperature. At Kiyoshi Kojin, exterior humidity was always lower than the interior. Marked differences between the forest exterior and interior were observed during the day. The greatest difference (18.5%) occurred at 14:00. At Taisanji and Nishinomiya Ebisu, night-time humidity was greater for the forest exterior than the interior, while day-time humidity was similar. At Kiyoshi Kojin and Taisanji, early-morning humidity recovered to nearly 100% in both the forest exterior and interior.

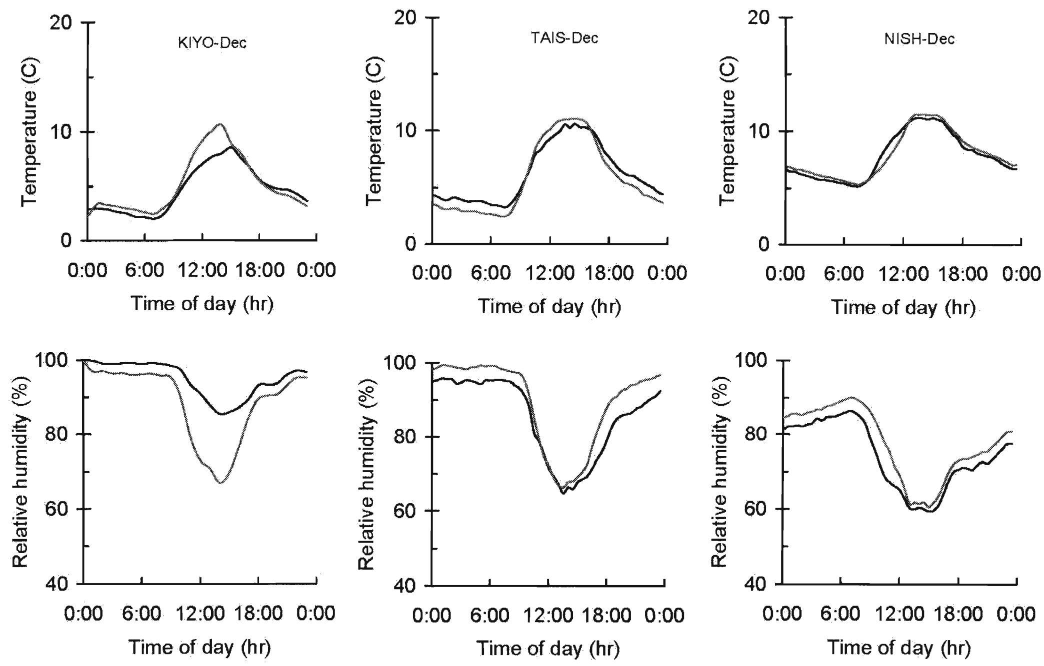

Fig. 4. Mean diurnal pattern of temperature and relative humidity of the forest exterior (gray line) and interior (black line) on clear days in December at the shrine/temple forest sites in southeastern Hyogo Prefecture.

Table 2. Description of the study sites.

Study site	Kiyoshi Kojin	Taisanji	Nishinomiya
Monthly mean temperature	ext > int	ext > int	ext >> int
Monthly mean humidity	ext > int	seasonal	seasonal
Diurnal variation	ext > int	ext >> int	ext >> int
Daily maximum difference	ext > int	ext >> int	ext >>> int
Night-time temperature	ext < int	ext < int	ext > int
Night-time humidity	similar	similar	ext < int

However, relative humidity never recovered to 100% at Nishinomiya Ebisu.

Discussion

The urban landscape surrounding Nishinomiya Ebisu recorded the highest temperature and lowest relative humidity, i.e., more extreme exterior conditions compared with the other two research sites (Table 2). At Nishinomiya, both maximum and minimum temperatures were higher for the exterior than the interior. By contrast, at Kiyoshi Kojin, surrounded by mountainous landscape, and at Taisanji, surrounded by suburban, rural landscape, interior conditions were relatively more stable than the exterior. I.e., monthly maximum temperatures were lower and minimum temperatures were higher for the interior. This indicated that, at Nishinomiya, conditions of the forest interior were more influenced by the surrounding urban landscape than at Kiyoshi Kojin and Taisanji, both of which are surrounded by vegetation.

Diurnal variation in temperature was greatest at Taisanji, suggesting that in suburban, rural landscapes there is a large difference between day-time and night-time temperature. In a mountainous landscape such as at Kiyoshi Kojin, thick vegetation cover mitigates night-time cooling. In an urban landscape such as Nishinomiya Ebisu, daytime heat may be stored in the concrete buildings and roads during the day and released slowly during the night. Both of these effects would result in less difference between day-time and night-time temperatures. Daily maximum difference in temperature between the forest exterior and interior was greatest at Nishinomiya Ebisu followed by Taisanji. This was because exterior temperatures at Nishinomiya Ebisu were higher than at other sites as the urban landscape accumulated large amounts of heat during the day.

The effects of the surrounding urban landscape on the forest at Nishinomiya Ebisu was especially marked during the summer months when urban landscapes accumulated heat during the day and slowly released it during the night. As was observed for the mean diurnal patterns during August, night-time exterior temperatures decreased more rapidly than the interior in mountainous and suburban landscapes at Kiyoshi Kojin and Taisanji. At Kiyoshi Kojin and Taisanji, temperature and relative humidity were more stable in the forest interior than in the exterior. As a result, day-time and night-time temperature relationships between the exterior and interior were reversed. However, at Nishinomiya Ebisu, although interior temperatures were lower and humidity higher, the diurnal pattern of the forest interior paralleled that of the exterior. Exterior temperatures remained higher than the interior, and exterior humidity was constantly lower than the interior even during the night.

Implications for conservation of fragmented shrine/temple forests

The results from Kiyoshi Kojin and Taisanji showed that microclimatic conditions inside native lucidophyllous forests are less variable than those of surrounding secondary forests, plantations and agricultural lands. The native lucidophyllous forests at Kiyoshi Kojin and Taisanji mitigate variable microclimatic conditions of the forest exterior and create favorable conditions for shade- and moisture-loving late-seral species. In a recent study, Manabe et al. (2003) investigated changes in stand structure and species composition over a 42-year period at a suburban shrine forest in northern Kyushu and found that many native species were preserved inside the fragmented native forest. Our results indicated that native lucidophyllous forests mitigate the harsh environment of the forest exterior and forest edge, and are important for conservation of late-seral species in increasingly human-dominated landscapes where they may otherwise become extinct due to the high occurrence of disturbances.

The results from Nishinomiya Ebisu illustrated the importance of evergreen shrine/temple forests in mitigating the microclimates of urban landscapes. In a series of studies conducted at Tsu Hachimangu Shrine in Mie Prefecture, Takeda et al. (1978; 1979; 1981; 1982; 1983; 1984) investigated the interactions between the shrine forest and the surrounding urban landscape. During their two-day study period, Takeda et al. (1978) found that microclimatic conditions were more stable in the forest interior than in the exterior. Our results showed that the artificial laurel forest at Nishinomiya Ebisu creates shady conditions within the harsh environment of the urban landscape that may function as refugia for plants and animals. However, at Nishinomiya Ebisu, interior conditions pararelled those of the forest exterior, whereas, at Kiyoshi Kojin and Taisanji interior conditions were more stable relative to the exterior. This suggested that the entire forest at Nishinomiya Ebisu may consist of edge environments. In their study of shrine/temple forests in Kyoto City, Murakami and Morimoto (2000) showed that small shrines and temples with less than 1 ha of forested area consisted entirely of edge environments. These results indicate that although shrine/temple forests may buffer the extreme microclimatic conditions of urban landscapes, their limited size may render them insufficient to create forest-interior conditions similar to native lucidophyllous forests. In addition, many urban shrine/temple forests suffer from invasion of non-forest species, such as *Trachycarpus* and *Sasa* from the surrounding landscape (Hagiwara, 1980; Manabe et al., 2003), suggesting that active management may be necessary to maintain near-natural conditions in urban shrine/temple forests.

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