Study on the Fire-Protection:
Characteristics of Green Spaces in Central Sakai City

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ABSTRACT

The purpose of this study is to include among close-at-hand shelter zones urban green spaces other than parks, and to examine the safety that those spaces provide against fires in terms of lot size, tree coverage ratio, and the fire-protection functions of trees. For our study we chose the district in Sakai City, Osaka Prefecture. This study found that because the tree coverage ratio, which affects a shelter zone's defense against fire, is changed by the effect of the tree canopy and not by lot size, it is necessary to use methods which ensure a good crown spread, such as planting tree species whose crowns spread well, improving pruning methods, and planting trees closer to the center of a lot. Our study also found that despite the small sizes of lots, many good fire-protection tree species had been planted.

Keywords: *Urban greenery, Private property, Fire, Shrine, Japan*

1. INTRODUCTION

Long before Japan had public parks, it had places which functioned as parks. In the Edo Period it was an integral part of the Japanese lifestyle to appreciate natural beauty and scenery and to delight in the seasons, and while Shinto shrines and Buddhist temples were places of religious faith, their grounds were also recreation spaces for the people, where religious festivals, events, and entertainment were held. After the Meiji Restoration the government tasked itself with building cities equal to those in the West, and in 1873 it implemented a public parks system pursuant to a Grand Council of State administrative order (Ishikawa, 2001). The first parks chosen by Tokyo Prefecture based on this order were the grounds of shrines and temples, which had always been recreation areas for the populace since the Edo Period. They were simply renamed as parks and functioned the same (Shirahata, 1991). Discussions by the Tokyo City Planning Council in 1885 proposed that the roles of parks be urban sanitation, magnificent urban scenery, shelter zones, morning and evening markets, and traffic mitigation. The council imagined diverse functions and purposes for them. Creating parks was a symbol of modernization, and it gradually spread throughout Japan (Ishikawa, 2001). In 1919, the Home Ministry surveyed the number of parks and their sizes nationally, finding that of the total 631 parks, 265 had been created from shrine and temple grounds, scenic places, former castle sites, and historical sites. By number these were about 40%, and by size about 80% of the total (Shirahata, 1991). Nevertheless, in terms of land area, privately owned green space not converted into parks since the Edo Period still accounted for much of the urban green space. Although it is said that parks were symbolically created using the stock of green space from previous eras and as part of introducing modern urban planning systems of Western origin, in terms of practical function it is privately owned green space not converted into parks that has played the main role as urban green space in Japan's cities. In particular, such green space is mainly stands of trees associated with shrines and temples, which have been selectively excluded from land development.

Some of the synonyms used in reference to the tree stands associated with Shinto shrines are "shrine forest," "guardian forest," "shrine/temple forest," "shrine woods," and "shrine precinct woods" (Fujita et al., 2007). Here we shall use "shrine/temple forest." According to Sakamoto et al. (1989), shine/temple forests perform two important roles: First, the very existence of shrine/temple forests functions as a forest environment, making the physical/chemical environment pleasant, providing a pleasant environment and a place for recreation, and serving as an underpinning for culture. Second, these forests have basic usefulness for maintaining existing forest environments and creating new ones. Some of these shrine/temple forests remained after land development, and they are of interest as the only clues enabling us to recreate the original vegetation of plains. In recent years, shrine/temple forests have been subjected to various impacts, including entry by people as urbanization advances, and problems associated with the forests becoming smaller, more isolated, and less natural (Shimizu et al., 2002). But it is said that shrine/temple forests play the same role as parks (Shirahata, 1991), are places which serve as foundations for establishing environmental conservation zones, and also have social significance such as their function in environmental conditioning and providing a spiritual foundation (Fujita et al., 2007). Because these shrine/temple forests are not under government management, they are not included in the total area of parks (Shirahata, 1991).

Incidentally, it is said that parks developed as cities grappled with the problems they faced (Masuda, 2003). In particular, there is a close connection to urban disaster prevention. Following the Kanto Earthquake it was found that plants functioned to protect against and mitigate disasters. In order to expedite urban disaster-prevention measures to take advantage of these functions of trees, research was conducted on the effects of trees in preventing the spread of fires and blocking radiant heat (Saito, 1994; Iwasaki, 2003). Further, various simulations have been produced for urban conflagrations. Shiraishi et al. (2001) analyzed the spread of fire using a spark scattering simulation, while Iwami (2009) proposed a way to calculate radiation heat flux at the time of an urban fire. When the 1923 Kanto Earthquake struck, people fled from the fire and took refuge in places such as plazas, schools, parks, shrine and temple grounds, and private residential lots (Fukushima, 1996). The safety of the places where they took refuge was affected by the presence or absence of trees. Salient examples of this are the grounds of the former army clothing factory (currently the Yokoamicho Park area) and the former Iwasaki mansion (currently Kiyosumi Garden). Both sites were subject to the same conditions: size, proximity to the Sumida River, surrounded by many private residences, and exposed to the heat of flames from spreading fire. They differed in that the former was a vacant lot, while trees had been planted on the latter. As the former army clothing factory site was a vacant lot, sparks coming from the surrounding area ignited the furniture, bedding, and other things people had brought when fleeing the fire, and resulted in three thermal whirlwinds which even lifted people into the sky. 38,000 people burned to death.

On the other hand, the former Iwasaki mansion was surrounded by a moat outside earthworks 3m high and 7m wide, on which many trees had been planted including *Castanopsis sieboldii* and *Machilus thunbergii*. The trees blocked the hot wind from outside and kept radiant heat from getting inside. Burning debris coming into the grounds was caught by the trees planted there. Thanks to these trees, the 20,000 people who took refuge there were safe. In other words, it was the parks, plazas, gardens, rivers, and other urban green spaces like the former Iwasaki mansion grounds which saved lives and kept the fire from spreading (Ishikawa, 2001). It is said that the 1995 Kobe Earthquake confirmed not only the effectiveness of trees in mitigating fire damage but also confirmed their effectiveness in other ways, such as in preventing the collapse of buildings, walls, and other structures; mitigating damage by debris falling from nearby buildings; serving as landmarks; supporting people living in evacuation sites; and their psychological effect. Wako et al. (1998) studied people's behavior when taking refuge in parks at the time of the Kobe Earthquake. They found that among those who fled to parks, there were people who evacuated temporarily to parks and those who chose parks as their evacuation homes, and that the primary reason both groups chose parks was proximity to their homes. In other words, when choosing an evacuation site they considered nearness to their homes important. Of those who temporarily evacuated to parks, 46.8% cited proximity to their homes as the reason for choosing parks, as did 36.8% of people living in parks. In view of these facts, it is considered important to upgrade the disaster-protection capabilities of parks and other green spaces near residences (Iwasaki, 2003). On the other hand, too little consideration has been given to the safety of near-at-hand shelter zones other than public parks, such as small privately owned open spaces (Kagiya & Ojima, 1998).

As noted above, the vegetation on privately owned land has an important place and plays an important role in Japan's urban development. The shrine/temple forests and farmland remaining in cities are valuable open spaces and much of that land is also privately owned (Katsuno, 2010). Nagino (2010) states that for cities to have much greenery it is necessary not only to secure public spaces, but also to take measures for conserving green space and encouraging the planting of vegetation on private land. Limits are now becoming apparent in the conservation and creation of greenery through public investments such as construction of parks, it is therefore thought to be increasingly important to conserve and plant greenery on private land, which accounts for the most area of cities. Urban green space, including that on private land, also plays an important role in preventing conflagrations and other disasters. The purpose of this study therefore is to define near-at-hand shelter zones as not only parks, but also private-sector spaces, Shinto shrines, and other urban green spaces besides parks, and to explore those shelter zones' safety against disasters, particularly fires, in terms of lot size, tree coverage ratio, and the fire-protection function of the trees planted there.

2. OVERVIEW OF STUDY AREA

For our study we chose the district (approx. 2.35 km^2) extending about 2.9 km from north to south, and about 1.1 km from east to west, from Kitahancho to Minamihancho in Sakai City, Osaka Prefecture (Figure 1). Our field survey covered a total of 18 sites comprising 10 parks, 4 private-sector spaces, and 4 Shinto shrines (Figure 2), which were within the study district and which could be near-at-hand evacuation sites. The "private-sector spaces" are privately owned green spaces provided as public facilities when apartment buildings or other such housing are built, in accordance with guidance standards for residential land and other development in Sakai City. Technical standards for these spaces call for 30% of the area being vegetation, with the remaining portion being bare land. Because these private-sector spaces are inside the development zones for apartments and other housing, from the apartment dwellers' point of view they are nearby open spaces just like block parks. Humans settled in what is now Sakai City from the Yayoi Period, and the coast developed as a fishing port through expansion and reclamation (Miura, 2006). The district covered by our study prospered as a moated city or free-trade city starting in the Muromachi Period by means of trade with China and with the Spanish and Portuguese. Even now parts of the moat remain. In the Edo Period, there was a passageway and drying ground along the east side of Sakai City's moat, and on the outside of the moat was a peasant district, and outside of that a temple district. Shrines were scattered among residences. This history is behind the large number of wooden structures still found in Sakai City. Overall, wooden buildings in the city outnumber non-wooden buildings by about 3 to 1. The ratio is about 2.3:1 if the comparison is limited to Sakai Ward, which includes our study district.

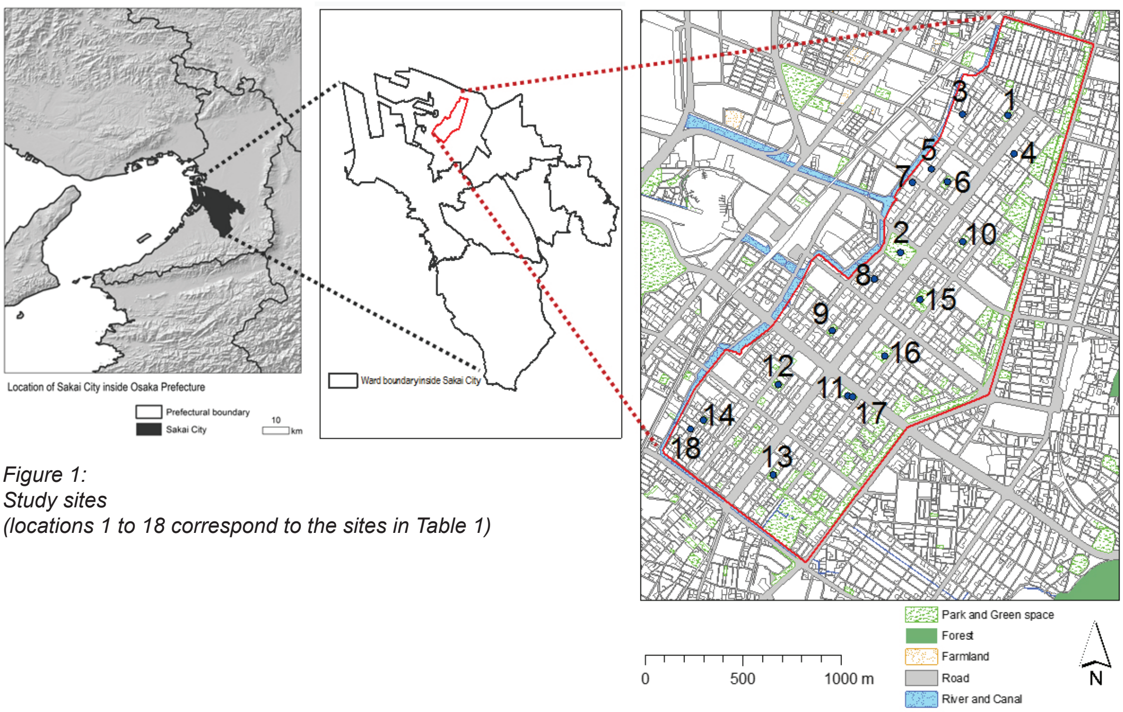


Figure 1:
Study sites
(locations 1 to 18 correspond to the sites in Table 1)

Figure 2:
Examples of green spaces surveyed in this study showing typical features.
(a) Shinzaike-cho Kouen, park,
(b) Azalea Kouen, private-sector green space,
(c) Sugawara Jinja, shrine grounds

3. METHOD

3.1 Local tree census

We performed a tree census of the total area of each lot in the study district. Each tree on a lot was checked for species, height, breast-height diameter, crown, multiple trunks, location, and fences. These 7 items were recorded even for saplings. Four items were recorded for dead trees: height, breast-height diameter, multiple trunks, and location. Breast-height diameter was measured at 1.2 meters from ground level. The breast-height diameter recorded for trees shorter than breast height was that for the position at which measurements could be taken. The breast-height diameter of trees with multiple trunks was determined to be 70% of the total breast-height diameters of all trunks. Locations of trees were checked on the basis of the general shape of the studied lots as determined by a rough survey before the study.

3.2 Area index measurement using GIS

Takahashi and Fukushima (1980) write, “It is desirable that the hierarchical structure of trees with good fire-protection functions have high vegetation coverage (ratio of projection area on the ground) horizontally in each stratum.” For that reason the tree coverage ratio would seem to be an indicator which influences the safety of nearby shelter zones. Because this study mainly considered a tree crown’s projection area on the ground, we used the tree coverage ratio. We used ArcGIS to calculate the tree coverage ratio based on pan-sharpened, false-color images from a commercial satellite launched in October 2009 (WorldView-2, with 50 cm panchromatic and 2.0 m multispectral resolution) and based on the positions of planted vegetation on each site. Our calculation method involved first determining tree crowns from satellite images and then preparing a polygon. We then used the ArcGIS geometry calculation function to find the polygon area. Of the area thus calculated, only that portion of the crown projection area inside a lot was taken to be the green coverage area. The following equation was then used to calculate the tree coverage ratio.

$$\text{tree coverage ratio (\%)} = \text{green coverage area } (m^2) \div \text{lot size } (m^2) \times 100$$

ArcGIS was also used to calculate lot size, but in consideration of error arising for small lots, sizes of private-sector spaces were taken from the signs posted on site.

3.3 Calculation of standing tree biomass, and assessment of fire protection potential

The implications of tree amount will be somewhat different depending on whether comparisons consider numbers of trees or numbers of tree species, or whether comparisons consider actual volumes. If one counts trees, then it is just a comparison of how many trees, but using volume enables comparison that includes magnitudes such as the height and breast-height diameter of individual trees. Takahashi and Fukushima (1980) think that tall trees not only have diverse hierarchical structures and greater leaf and branch amounts, but also greater fire-protection functions such as moisture release, blocking and dispersion effects, and catching of burning debris. It is therefore expected that tree biomass not only shows the amount of growing trees in a nearby shelter zone but also indicates the fire-protection function that is dependent on tree height.

Tree biomass is the volume of the trunk with all branches deducted. In this study we calculated standing tree biomass using the simplified method in this equation:

$$v = 3.14 \times (dm/200)^2 \times h \times fm$$

where:

v is tree biomass (m^3)
dm is breast-height diameter (cm)
h is tree height (m)
fm is the breast-height factor

Our breast-height factor was set to 0.5238 based on Nagumo and Miwa (1990).

3.4 Determining species-specific fire-protection function

Characteristics of trees differ from one species to another, and therefore tree species affect the safety of shelter zones (Takahashi & Fukushima, 1980). For this reason we scanned the existing literature for data from experiments on the fire-protection functions of trees during conflagrations in order to determine species-specific fire-protection functions. We used existing experimental data on three criteria. We referred to Iwasaki (2003) on flammable gases, Iwasaki (2007) on shape-change rate, and Iwasaki (2005) on moisture content. These experiments had been performed anew based on previous experiments, and are likely the most recent research data on the fire-protection functions of trees. Based on these data, we categorized our tree census results into trees with high and low fire-protection functions.

Flammable gases means gases that will burn in the presence of air, such as propane, methane, and coal gas. Trees which, soon after fires start, emit large amounts of the CH compounds that are the representative constituent of flammable gases, and which ignite without flame in a short time, give off much flammable gas and are therefore thought to ignite and burn readily. They also readily ignite in the presence of flame. This shows that ignition is related to the amounts of flammable gases emitted. In this study, trees that emit large amounts of flammable gases are considered to have an inferior fire-protection function, while those that emit small amounts or small amounts of flammable gases are considered to have a superior fire-protection function.

When leaves lose their moisture, they wilt and change shape, and the differences in their rate of shape change make for differences in their abilities to sustain their heat-shielding effect. For example, if leaves do not maintain their shapes when resisting the heat of fire, their heat-shielding effect declines. And a high rate of shape change means a large shrinkage ratio in the leaves' maximum projection area. Thus such trees would likely have little capability of a sustained heat-shielding effect, that is, they could sustain a heat-shielding effect for only a short time. On the other hand, trees with a low shape-change rate would likely have the capability of a sustained shielding effect, that is, they would sustain their shielding effect for a long time.

The moisture in leaves helps prevent temperature rise when exposed to heat. When the temperature is below approximately 100°C, the moisture stored in leaves either evaporates or transpires as temperature rises due to radiant heat. It is presumed that the longer that temperatures below 100°C are maintained, the greater the effect of the retained moisture. Evergreen broadleaf trees are regarded as having long moisture retention time, while deciduous broadleaf trees have a comparatively short moisture retention time. And because the combustion rate of wood is inversely proportional to the cube root of its moisture content, the fire-protection capability of trees is thought to be highly dependent on moisture. This research regards trees with high moisture content as trees with a superior fire-protection function, and trees with low moisture content as trees with an inferior fire-protection function.

4. RESULTS AND DISCUSSION

4.1 Relationship between lot size and tree growth

Table 1 shows the field survey results. It is evident from the graph showing the relationship between lot size and number of trees (Figure 3) that the larger the lot, the more trees there are. The same tendency is seen in the graph showing the relationship between lot size and the number of tree species (Figure 4); the larger the lot, the more tree species there are. A result of the research by Shimizu et al. (2002) on the vegetation structure of shrine/temple forests in Sakai City was that changes in the number of species correspond to increase or decrease in lot size. Our research also found this correspondence between the number of tree species and lot size, including in private-sector spaces and parks. Therefore this vegetation structure applies not only to shrine/temple forests, but also to private-sector spaces and parks.

We discerned no regular relationship between lot size and tree coverage ratio (Figure 5). For example, study site 8 was 133 m^2, making it the smallest of all, but its tree coverage ratio was 14%, or 1 percentage point higher than the lowest ratio of 13% held by site 17, whose size was 1,495 m^2. The largest site, site 2, was 14,265 m^2 in size, or about 2.4 times larger than site 15, which was the second-largest. However, the tree coverage ratio of site 2 was 64%, making it only the fourth-highest. There are three conceivable reasons for this. First, it might be attributable to the number of trees. A small number of trees mean few trees on a site, which results in a low tree coverage ratio. For example, site 17 had the lowest tree coverage ratio, and also the smallest number of trees at 21. Second, because the tree coverage ratio shows the proportion of tree crown projection area with respect to lot size, presumably the ratio changed depending on the number of trees making up the canopy. Our field tree census found that the canopy is composed mostly of camphor laurel, zelkova, cherry, and chinaberry. Some of these trees had crowns as much as 6 m in radius. However, while the largest-radius crown in site 8 was 1 m, some of the crowns in site 17 were larger than 1 m. Therefore this reason does not apply to the relationship between sites 8 and 17. There is another reason, which shall be discussed in the following section. Third, there is a likely connection to tree location. When trees are planted only around a lot's perimeter, it is hard for a canopy to form in the lot's interior. On the other hand, if trees have been planted in the interior, they will make up a canopy in the interior, which will accordingly heighten the tree coverage ratio.

As seen above, while the number of trees and number of tree species depend on lot size, there is no consistent relationship between lot size and tree coverage ratio. In other words, there are sites with high tree coverage ratios and those with low ratios, which are not affected by lot size. Therefore increasing the number of trees is one way to raise the tree coverage ratio, but because densely growing branches and leaves have a good fire-protection function as observed by Takahashi and Fukushima (1980), it would seem most important to have a good spread in the crown of each tree, and have their leaves and branches overlapping well. It also seems important to create a good tree coverage ratio by planting trees also in the lot interior instead of just round the lot perimeter.

Table 1: Results of field survey

Study site	Name	Landholding	Size (m^2)	Number of trees	Number of tree species	Tree coverage ratio (%)	Tree biomass (m^3)
1	*Nishiki-nishi Kouen*	Park	1,648	106	20	75	17.08
2	*Ebisu Kouen*	Park	14,265	513	56	64	96.43
3	*Yanagino-cho Aoki Kouen*	Park	292	30	17	37	1.05
4	*Yanagino-cho Ikoi no Hiroba*	Private sector	173	30	9	14	0.32
5	*Grand Blue*	Private sector	156	35	14	13	0.34
6	*Shukuya-cho Kouen*	Park	2,012	71	12	83	20.07
7	*Sakai Daisan Goudou Shukusha Jidou Kouen*	Private sector	180	34	13	15	0.11
8	*Azalea Kouen*	Private sector	133	34	10	14	0.15
9	*Kaino-cho Kouen*	Park	1,710	58	24	28	2.00
10	*Zaimoku-cho Kouen*	Park	2,100	98	26	37	5.27
11	*Shukuin-cho Kouen*	Park	1,971	124	35	71	20.07
12	*Nakano-cho Kouen*	Park	2,064	94	34	46	5.93
13	*Shinzaike-cho Kouen*	Park	2,281	132	37	52	1.54
14	*Shinzaike Nishi Hiroba*	Park	976	34	15	43	1.11
15	*Sugawara Jinja*	Shrine	5,913	216	37	35	38.37
16	*Aguchi Jinja*	Shrine	4,438	152	38	36	36.50
17	*Sumiyoshi Taisha Shukuin Tonguu*	Shrine	1,495	21	9	13	1.31
18	*Aguchi Jinja Ashihara Otabisho*	Shrine	575	49	15	57	3.66

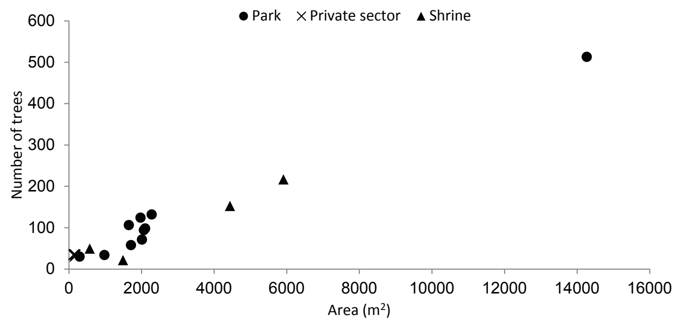


Figure 3:
Relationship between lot size and tree numbers by landholding type

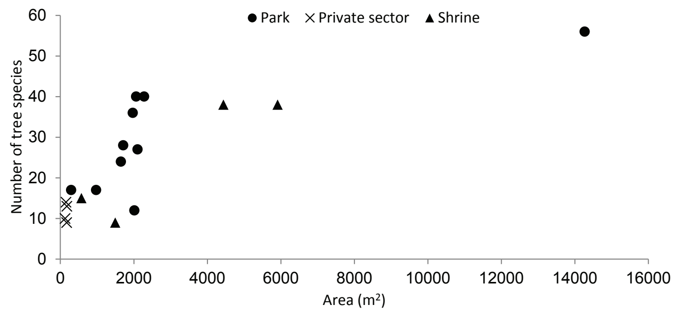


Figure 4:
Relationship between lot size and tree species by landholding type

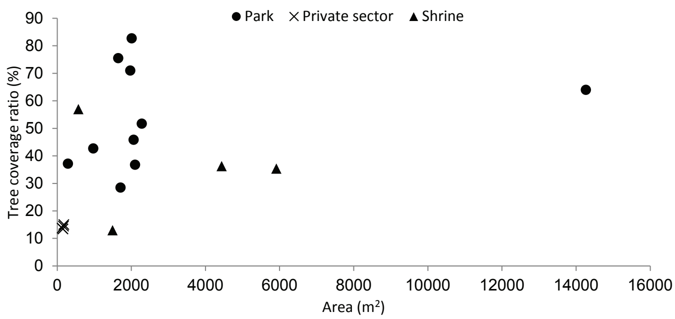


Figure 5:
Relationship between lot size and tree coverage ratio by landholding type

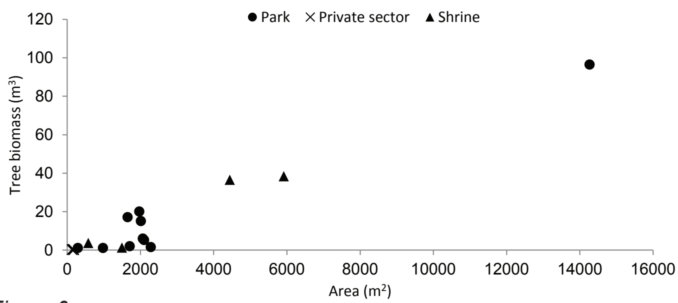


Figure 6:
Relationship between lot size and tree biomass by landholding type

4.2 Relationship between landholding type and state of tree growth

According to Table 1 and Figure 3, the lowest number of trees in a private-sector space was 30, and the highest was 35. In parks the lowest was 30 and the highest was 513, for an approximate 15-fold difference. Parks had more trees than private-sector spaces. The park with the maximum number of trees was site 2 and the following discussion will exclude that value, which gives parks a maximum 120 trees and substantially shrinks the difference with private-sector spaces to a factor of 4. On shrine grounds, the lowest number of trees was 21 and the highest was 216. The lowest number for shrines was the lowest value in terms of landholding type, and the highest number was the highest value. In other words, because there is a difference of at least 3,000 m^2 in lot size between sites 17/18 and 15/16, there was also a difference in the number of trees at shrines depending on the site. We examined private-sector spaces and parks in the same way. In the case of private-sector spaces, differences in lot size were under 50 m^2, and as such there were no differences in numbers of trees. For parks, because there were many sites and because the distribution of lot sizes was from 300 m^2 to 2,300 m^2, at first glance it looks as though there is no difference in the number of trees. But actually there was a 100-tree difference. Comparing the average number of trees per site found that parks had the most at 121, while shrines had 110. Private-sector spaces had 33, which was fewer than the other site types by a factor of about 3 to 3.5. Although private-sector spaces had the fewest trees, they had the most trees per unit area (0.84 trees/m^2). Second was parks with 0.52 trees/m^2 and shrines with 0.17 trees/m^2. In view of the fact that small lot size limits the amount of open space where trees can be planted, it would seem there is a tendency to plant trees densely. In sum, because the number of trees is influenced by lot size, there was variation in the number of trees even among sites of the same landholding type. Also, the total number of trees specific to each landholding type and the average number of trees per site were naturally high for large lot sizes.

According to Table 1 and Figure 4, the tree species on private-sector spaces numbered 9 at the lowest and 14 at the highest. Parks were 12 at the lowest and 56 at the highest. Shrines were 9 at the lowest and 38 at the highest. The park with the maximum number of tree species was site 2, and if that value is excluded, the highest number of tree species for parks is 40, and that for shrines approaches 38. The number of species for shrines shows the same tendency as the number of trees, and there was a difference in the number of species depending on the site, in accordance with the difference in lot size between sites 17/18 and 15/16. In other words, just as with the number of trees, the number of species was influenced by lot size, and therefore there was variation in the number of trees even among sites of the same landholding type. The number of tree species appearing by landholding type had the same tendency as the number of trees, with the numbers highest in parks, followed in descending order by shrines and private-sector spaces. There were 137 species in parks, 68 in shrines, and 33 in private-sector spaces.

According to Table 1 and Figure 5, the lowest tree coverage ratio for private-sector spaces was 13% and the highest was 15%. With the other two locations being 14%, all private-sector spaces had about the same ratio. For parks the lowest ratio was 28% and the highest was 83%. For shrines the lowest was 13% and the highest was 57%. The tree coverage ratio per site was highest for parks at 55%, followed by shrines at 35% and private-sector spaces at 14%. Differences in landholding type means differences in tree management, and it is possible that this led to differences in tree crown development. A conspicuous method of tree management was the way the branches of large trees were pruned. Among parks, site 12 had two of its 94 trees pruned, or 2%. Among shrines, site 15 had 17 of its 216 trees pruned, corresponding to 8% (Figure 2c). Trees in private-sector spaces had been shaped. Figure 2b shows the trees planted in site 8, a private-sector space. As one can see from this photograph, tree crowns are somewhat spread out, but because branch ends had been pruned, leaves were mostly on the top, and balance is lost between trunk length and the vertical length of the crown. Takahashi and Fukushima (1980) write, “It is desirable that the hierarchical structure of trees with good fire-protection functions have high vegetation coverage (ratio of projection area on the ground) horizontally in each stratum.” Therefore, because the tree coverage ratio used in this study has the highest values for parks, parks would appear to be spaces with better fire-protection functions than those of private-sector spaces and shrines. And according to Saito (1996), because the function of trees as shields is influenced by the state of crown development, it is desirable from the perspective of fire protection to plant trees so that tree crowns completely cover the entire grove. From this it follows that parks with high tree coverage ratios, and especially study sites 2 and 6, which on the occasion of our tree census gave the impression of having their lots covered with well overlapped tree crowns, are safe areas in view of their crown development.

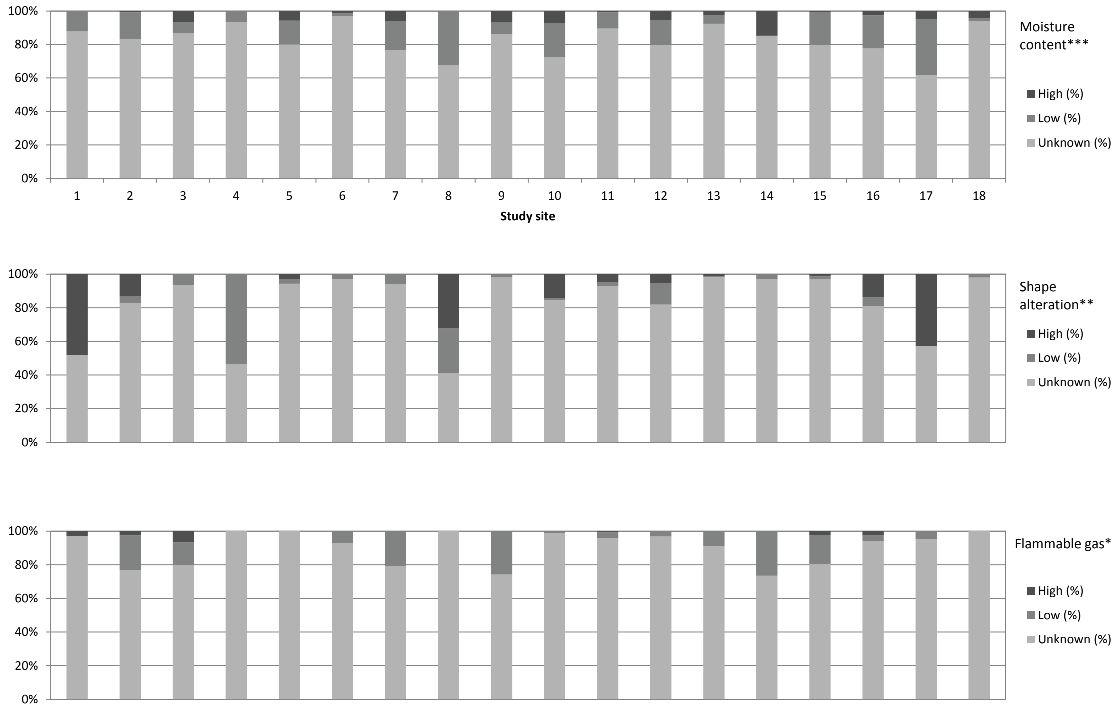
Biomass totals were 171 m^3 for parks, 80 m^3 for shrines, and 1 m^3 for private-sector spaces (Table 1, Figure 6). These values saliently show the character of private-sector spaces, which are adjacent to apartments and where the growth of trees is suppressed from the perspectives of consideration for the adjacent apartment buildings and for crime prevention. Tree growth is not suppressed in parks perhaps because parks are surrounded by streets, so that even if tree crowns reach the streets, they do no harm to residences. Additionally, the private-sector spaces covered by this study were presumably created after the Sakai City guidance standards for residential land development, which were enacted in 2003. Little time has passed since their trees were planted, which would explain their small size. Hence, biomass was small presumably because tree size was kept small and many trees smaller than medium size were planted. Shrines had the most biomass per site, at 20 m^3, followed by parks at 17 m^3 and private-sector spaces at 0.3 m^3. This is an indication of the large trees on shrine grounds. Private-sector spaces had the smallest biomass per unit area, at 0.0056 m^3/m^2. Parks had 0.047 m^3/m^2 and shrines had 0.022 m^3/m^2. Because biomass was calculated from tree height and breast-height diameter, small biomass means that tree height and breast-height diameter were small. According to Takahashi and Fukushima (1980), large trees not only have diversified hierarchical structures and increased leaf and branch amounts, but also greater fire-protection functions such as moisture release, blocking and dispersion effects, and catching of burning debris. It follows that public-sector spaces, which have much lower biomass than parks and shrines, also have inferior fire-protection functions.

4.3 Assessment of fire-protection functions due to tree-species composition

With regard to the three criteria of flammable gas emissions, shape change rate, and moisture content, and without regard to landholding type, the proportion of trees with excellent fire-protection functions was not high, while the proportion of trees designated as “unknown” and having neither superior or inferior fire-protection functions was high (Figure 7). This suggests that it is of course necessary to carefully choose species to plant, but also that it is important to raise the proportion of trees with superior fire-protection functions. We compared the proportions of trees with superior and inferior fire-protection functions, and, using a lot size of 1,000 m^2 as the standard, compared the numbers of study sites with high proportions of trees having superior fire-protection functions. With regard to flammable gas emissions, 29% of sites that were under 1,000 m^2 in size were planted with many trees having superior fire-protection functions, while the proportion was 82% for sites that were 1,000 m^2 or larger. With regard to shape change rate, the proportions were 71% for the former and 36% for the latter. For moisture content, the figures were 29% for the former and 0% for the latter. These percentages show that in connection with shape change rate and moisture content, sites smaller than 1,000 m^2 had more trees with superior fire-protection functions than sites of 1,000 m^2 or more. The smaller the lot size, the smaller the number of trees and number of tree species it had; therefore, small sites were inferior in terms of lot size. However, on the other hand, because they have higher proportions of trees with superior fire-protection functions, they are conceivably spaces of great safety in terms of species composition. In particular, although private-sector spaces are more dangerous than parks and shrines in terms of tree coverage ratio and biomass, in terms of species composition it would be hard to say they are dangerous in view of their small number of trees with inferior fire-protection functions.

5. CONCLUSION

This study found that although number of trees and number of tree species depended on lot size without regard to landholding type, there was no consistent relationship between lot size and tree coverage ratio. Therefore it would seem that to improve fire-protection functions by using the tree coverage ratio makes it important to have a good tree-crown spread, and ways to do that include using pruning techniques that encourage crowns to spread, using species with spreading crowns such as camphor laurel, and planting trees in places that allow their crowns to spread. We found that for all indicators except the number of trees per unit area, private-sector spaces had the lowest values. Considering that it is said that high tree coverage ratio and tree height provide superior fire-protection functions (Takahashi & Fukushima, 1980), parks and shrines with their high tree coverage ratios and biomass presumably have better fire-protection functions than private-sector spaces. Tree growth as seen in crown development, tree coverage ratio, and tree height appear different at each site owing to 3 influences: the state of management at each site, the



** based on Iwasaki (2003); ** based on Iwasaki (2007); and *** based on Iwasaki (2005)*

Figure 7:
Tree planting ratio according to fire resistance

surrounding environment such as the arrangement of residential buildings and roads, and the length of time elapsed since the site was given maintenance. Therefore giving a space good fire-protection functions especially requires maintenance based on the environment surrounding each site because the conditions at a site change depending on the surrounding environment.

Overall, the proportion of trees with excellent fire-protection functions was not high, while the proportion of trees designated "unknown" and having neither superior nor inferior fire-protection functions was high. This suggests that it is of course necessary to carefully choose what species to plant, but also to pay attention to the proportion of trees with superior fire-protection functions. With respect to shape-change rate and moisture content, we found that lots smaller than 1,000 m^2 in size had more trees good for protecting against fires than lots of 1,000 m^2 or larger. The smaller the lot, the fewer trees and tree species it had, and therefore small lots were inferior when considered in terms of lot size. But because they had a high percentage of trees that are good for fire protection, they are presumably very safe spaces in terms of tree species composition.

The Sakai City Basic Green Plan and Urban Planning Master Plan are initiatives which promote the greening of the city, but the city has no guidelines on greenery management from the perspective of protecting against fires at the time of disasters. For that reason it is necessary to take advantage of this study's findings and create urban green spaces that take fire-protection into consideration based on the surrounding environment and other factors such as landholding type, lot size, the building materials of nearby residences, and their building coverage ratios, and it is vital to create greenery management guidelines. It is also important to have individuals, as well as businesses and other organizations, incorporate the perspective of fire-protection into the greenery around residences and buildings, and for that purpose offer them a list of tree species to plant which are recommended for their fire-resistance, thereby attempting fire-protection measures with community involvement.

Sakai City has a long history and consequently has a considerable number of historic temples and shrines as well as public parks and private-sector green spaces resulting in a mosaic of urban greenery (Figure 1). Given this historical context, Sakai City might have more diverse green spaces than other ordinary Japanese cities. Nevertheless, it can be said that in other cities, too, temples, shrines, public parks, and private-sector green spaces are the main components of urban greenery, even though the spatial scale of the mosaic might differ. Hence our research framework is likely to be applicable to other Japanese cities. Further case studies in a variety of different cities will be needed to confirm the validity of our research framework.

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