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Dimensions and Management of Remnant *Garcinia subelliptica* Tree Belts Surrounding Homesteads

- A Case Study from Two Villages on the Sakishima Islands, Okinawa Prefecture, Japan –

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Abstract: This study aimed to compile an inventory of remnant old growth trees that were planted along the border of homesteads as windbreaks, and to explore the conservation status of these old growth trees. Two survey sites in the southernmost part of Okinawa Prefecture, Japan, were selected. We found that the tree line at the north and east sides of homes have been protected and were better conserved than the tree line at the south and west sides. The average tree density was approximately 0.8 ± 0.32 (SD) trees per meter for well-preserved tree belts. Moreover, a negative correlation between tree density and mean DBH size was found at both the east and north sides. The conservation and maintenance of old growth trees within the homestead depends on natural and human factors. Exposure to typhoons and monsoonal winds are among the most important natural factors that contribute to tree damage. However, human factors are also important in terms of tree cutting or conservation. The residents' awareness on tree conservation determined whether trees were preserved or felled.

Key words: environmental conservation, old growth trees, rural landscape, small plot of trees, tree belts along the homestead

1 Introduction

In order to protect settlements and farmland in the coastal areas of Okinawa from strong winds, a traditional rural landscape with multilayered tree belts was created approximately 300 years ago. This landscape was constructed according to the Chinese *fengshui* concept, with *hougo* (embraced protection) as its key principle (Chen et al. 2008). Before the Second World War, coastal forest belts and homestead windbreaks were widespread on the Ryukyu Islands. These huge trees, which were planted during the Ryukyu Kingdom Period, are prevalent inside and near villages on the Ryukyu Islands (Chen and Nakama 2011a, b). However, most of the forest belts vanished because of war fires and recent land development to consolidate fragmented farm lands, and windbreaks were cut to facilitate machine use and car transportation. The traditional village landscape should be re-evaluated as a cultural heritage and its function to provide significant ecosystem services in the coastal regions should be assessed.

The first step necessary to propose that the remnant trees possess cultural properties is to understand the inventory, location, and dimensions of the existing trees surrounding houses. In our previous study, we have inventoried the remnant trees on mainland Okinawa and a few small islands nearby, and explored their cultural and historical significance; in addition, we have compiled measurements of the remnant tree belts along the borderlines of the homesteads in several villages near the mainland of Okinawa, such as Bise and Imadomari in the north, and Aguni Island and the Tonaki Islands (Chen and Nakama 2011c). This study was part of a survey of the inventory of the remnant *Garcinia subelliptica* (Fukugi)[1)] trees on the Ryukyu Islands. In the present study, we extended our survey to two villages on the Sakishima Islands, with the aim of clarifying the current state and spatial distribution of homestead tree belts located on these isolated islands in southernmost Okinawa Prefecture.

2 Survey sites and methodology

In this study, two villages located on the Sakishima Islands of Okinawa Prefecture were surveyed: Hateruma, the southernmost inhabited island of Japan, and Karimata, located at the northernmost part of Miyako Island (Figure 1). The two villages were selected because both of them are under the extremely strict natural environment, and have the well preserved tree belts.

Hateruma Island (24°2′25″N, 123°47′16″E) belongs to the town of Taketomi in the Yaeyama District of Okinawa Prefecture, Japan. With an area of 12.7 km^2, it is composed of corals, and is oval in shape, measuring 3

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km wide from north to south and 6 km from west to east.

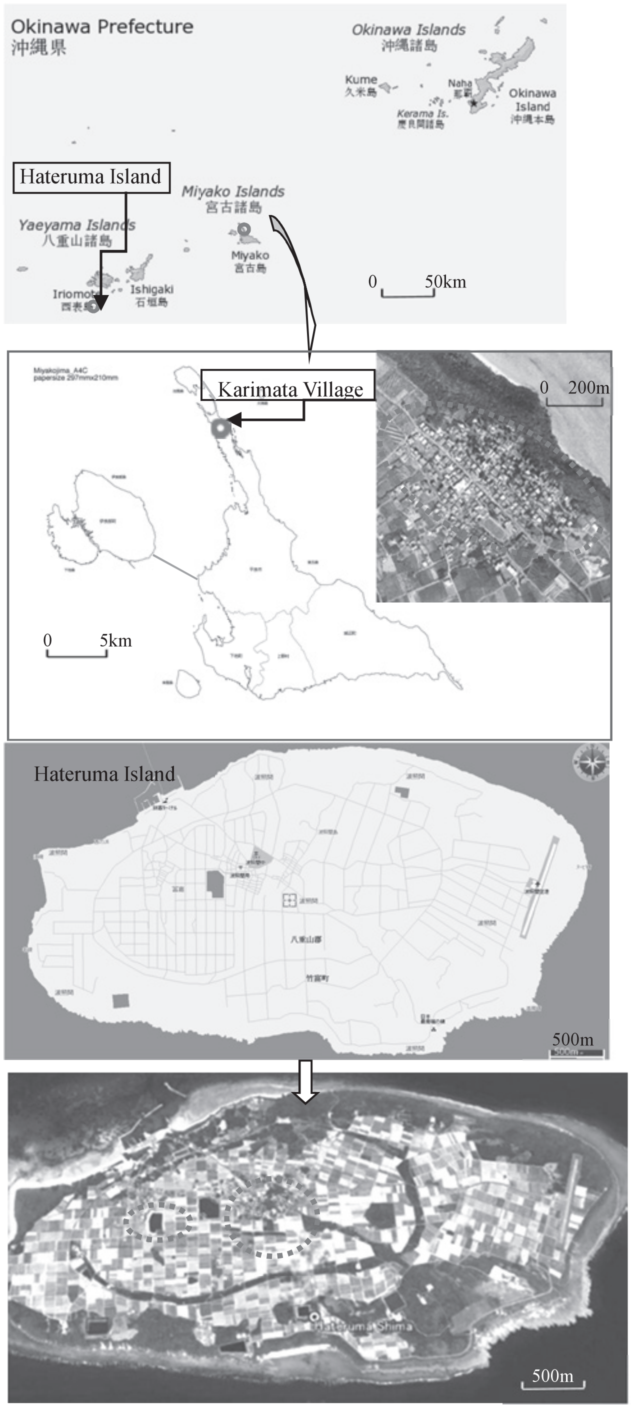


Figure 1 Location of the survey sites

presents the part with Fukugi tree lines that were surveyed

Source: The aerial photos are from Google earth.

Map of Miyako Island was edited based on data from the homepage of http://technocco.jp/; and the map of Hateruma Island is edited based on the data by Zenrin Cooperation.

The center of the island is the highest part at 60 m above sea level, and the coastal line is the lowest part. Hateruma Island is composed of five sub-hamlets: Naishi, Mae, Kita, and Minami at the center of the island, and Fuka in the west. As of June 2016, the island's population was 509 people (Taketomi Town Office). The major crop is sugarcane, and some local species of millet, red beans, sesame, etc., are planted on the island. Sugar processing is the major industry. As a popular tourist destination, Hateruma Island accommodated approximately 34,744 tourists in 2014 (Taketomi Town Office).

Karimata village (24°52′40′N, 125°16′56″E) has an area of 7.1 km^2. It is located at the northernmost part of Miyako Island, which is the fourth-largest island in Okinawa Prefecture, with an area of 158.7 km^2, and lies approximately 300 km southwest of Okinawa Island. As of December 2015, the population of the village was 600 people (Miyako City Office). The major crop is sugarcane, and some other crops, including tobacco leaves, mango, and peanuts, are also cultivated.

Field surveys were conducted to obtain the following characteristics of each tree: diameter at breast height (DBH), height, and cardinal direction within each village. All Fukugi trees in the villages were surveyed, and the DBH was determined at a height of 1.3 m; only trees with a DBH larger than 5 cm were surveyed. Tree height was also measured and recorded. Tree age was estimated based on the DBH. All Fukugi trees with DBHs larger than 25 cm were estimated to be approximately 100 years old, and were considered to have been planted during the Ryukyu Kingdom Period (1429–1879) (Chen and Nakama, 2011c). There are two methods for estimating the age in Fukugi trees: Equation (1) proposed by Hirata (2006), and Equation (2) deduced by Nakama *et al.* (2014):

$$y = x_1 \div 2 \times 8 \quad (1)$$

$$y = x_2 \div 2 \times 6.2 \quad (2)$$

where y is the estimated tree age, x_1 is the DBH (cm) at the height of 1.3 m above ground, and x_2 is diameter (cm) at the height of approximately 0.2 - 0.3 m above ground.

We adopted the original (1) Hirata method as we only measured the DBH in the field. Considering a possible deviation in the tree's estimated age against its real age, age classes of 50 years were used in the analyses.

The biggest Fukugi trees present in all surveyed houses were indicated on a residential map published by Zenrin, a large company specializing in Japanese residential maps. The surveyed trees have been classified into four groups according to their estimated ages: 100-150 years old; 151-200 years old; 201-250 years old; and 251-300 years old. The actual distribution of tree age groups was mapped by house and is presented in different colors. The spatial distribution of the tallest Fukugi trees within each property was mapped. We assume that house owners selectively cut Fukugi trees for special purposes, and some trees may have died due to strong typhoons; however, the locals did not clear-cut all trees in a line in order to maintain their windbreak function, allowing the oldest trees to survive, thereby providing historical data regarding residential land evolution.

In addition, the appearance of Fukugi tree belts, as well as other species of trees planted along the homestead, was also marked in different colors on the map. In order to determine the appropriate tree density, only well-preserved tree belts were surveyed and used to calculate tree density.

Interviews with local knowledgeable people and the community center head in Hateruma Island were conducted to clarify the current state of tree management.

The field survey at Karimata (Miyako Island) was conducted in August 2014, and the surveys on Hateruma Island were conducted three times: August of 2014 and 2015, followed by a supplementary field survey in December 2015. During each survey, the heights and diameters of trees were measured; however, we were unable to measure the diameter of a few trees in the field. Therefore, the numbers of trees used in the analyses are slightly different.

3 Results and discussion

3.1 Tree age and height

Fukugi trees on Hateruma Island were in much greater numbers than those at Karimata. In total, 3,036 and 1,369 trees were measured in the villages of Hateruma and Karimata, respectively. The number of Fukugi trees surveyed on Hateruma Island was almost three times that of Karimata.

A distribution graph of tree ages and heights is given in Figures 2 and 3. In general, Fukugi trees had greater diameters and were older on Hateruma Island, than those at Karimata (Table 1). The mean tree age was estimated at 112.8 and 92 years in Hateruma and Karimata, respectively. As shown in Table 1, approximately 1,796 (63.5%) of the trees surveyed were more than 100 years old in Hateruma, whereas only 586 (42.9%) were older than 100 years old in Karimata; however, the biggest tree found in Hateruma and Karimata was estimated to be 266 and 268 years old, respectively. In other words, Fukugi trees were planted as homestead tree belts at similar time on the two surveyed islands. The biggest tree on Hateruma Island was found in the sub-hamlet of Mae. Therefore, because Fukugi trees were smaller, on average, and fewer at Karimata than Hateruma, it can be assumed that Fukugi trees were better maintained and conserved on Hateruma Island than Karimata. Differences in topographical and geographical features are attributed to differences in tree maintenance. One side of Karimata borders a hill in the north, whereas the five sub-hamlets of Hateruma are all located at the highest spot on the island and are exposed to the strong winds from all directions (Figure 1). The tree belts on Hateruma Island provide protection to houses from ocean winds.

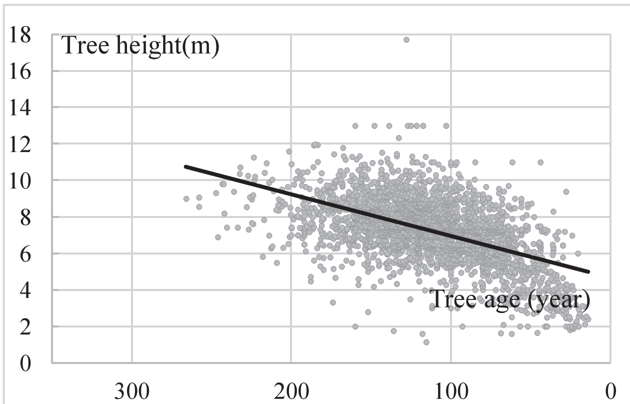


Figure 2: Distribution of tree age and tree height in Hateruma Island

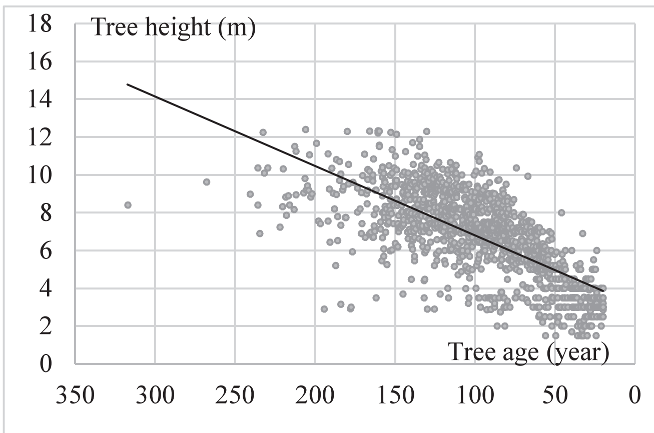


Figure 3: Distribution of tree age and tree height in Karimata Hamlet

Fukugi trees were managed at a lower height in Karimata than Hateruma Island (Table 2). The trees surveyed at Hateruma were 7.2 m tall on average, whereas the mean tree height was only 6 m at Karimata. The height of most trees varied between 6 and 10 m in both villages, which equates to 76.1% at Hateruma and 55.5% at Karimata. However, trees shorter than 4 m were much more prevalent at Karimata (21.1%) than Hateruma (4.8%). It is difficult to say whether trees pruned to be shorter than 4 m can serve as effective windbreaks. Therefore, the fact that owners chopped tree branches, only keeping the tree stem at an extremely low height, suggests that the trees were considered useless and may be clear-cut in the near future. The removal of trees planted by ancestral peoples for windbreak purposes is frequently witnessed on the two survey sites and on other islands; when the older generation passed away, the homestead was inherited and managed by younger generations.

The tallest trees were 17.7m and 12 m at Hateruma and Karimata, respectively. The tallest tree measured in Karimata was located on unmanaged land without any buildings. Similar to Karimata, the tallest tree in Hateruma was located on a property with an abandoned house in the sub-village of Mae.

Table 1: Descriptive data of Fukugi trees by estimated age (year) in two survey villages

Survey site	Total no	Mean	Max	Tree number by estimated age (year)						
				0-50	51-100	101-150	151-200	201-250	251-300	301-
Hateruma	2,825	112.8	266	188 (6.7)	841(29.8)	1278 (45.2)	463 (16.4)	52 (1.8)	3 (0.1)	0 (0)
Karimata	1,369	92	317	304 (22.2)	479 (35.0)	434 (31.7)	123 (9.0)	27(2.0)	1 (0.1)	1(0.1)

Note: Number in () presents the percentage

Table 2: Descriptive data of Fukugi tree height in two survey villages

Survey site	Total no	Mean (m)	Max (m)	Number by tree heights (m)						
				0-2	2.1-4	4.1-6	6.1-8	8.1-10	10.1-12	12.1-
Hateruma	3,014	7.2	17.7	10 (0.3)	136 (4.5)	443 (14.7)	1,409 (46.7)	886 (29.4)	119 (3.9)	11(0.4)
Karimata	1,369	6.4	12	20 (1.5)	268 (19.6)	238 (17.4)	420 (30.7)	339 (24.8)	74 (5.4)	10 (0.7)

Note: Number in () presents the percentage

3.2 Cardinal direction of tree stands

The cardinal directions of Fukugi tree stands are summarized in Table 3. With the house as the center of the homestead, the direction that the trees were orientated was tallied as north, south, east, or west. Because almost all the homesteads were arranged in squares, the four lines at the perimeter of each homestead were split into four directions during the field survey; however, in this regard, north does not necessarily correspond to true north.

We found that the majority of Fukugi trees stood north and east, although there were slight differences between the two villages surveyed. In Karimata, the majority of trees were orientated north, followed by east, whereas the fewest trees were orientated south. In comparison, the majority of trees at Hateruma were orientated east (35.9%), followed by north (33.4%).

The results showed that the trees were purposely maintained on the north and east side, which is where typhoons strike the village strongly from the two survey villages were consistent with the other case study conducted in Mainland Okinawa. Our results are different from previous studies in that most trees were measured on the east side of Hateruma, although the differences were not large (32.4% north and 36.9% east). From the geographical location, we can see that both villages must have suffered significantly from monsoonal winds on their north sides, as one location is a small isolated island and the other is located at the northern tip of Miyako Island. Typhoons from the east side have also destroyed houses.

3.3 Tree belt coverage and tree density

We observed that the majority of houses in Hateruma were enclosed by Fukugi tree lines or other tree species. In Figure 4, the tree belts were drawn at lengths proportional to their true distribution. Except the sub-village of Fuka, the four sub-villages of Naishi, Mae, Kita, and Minami had a high coverage of trees. In contrast, tree belts were much fewer and shorter in Karimata. In addition to Fukugi trees, other plant species were also used as homestead windbreaks, among which *Diospyros egbert-walkeri* was also common, and *Murraya paniculata*, *Calophyllum* *inophyllum*, *Podocarpus macrophyllus*, and *Rhaphiolepis indica* were also planted, although very rarely, around houses on Hateruma Island. These trees have been very useful and utilized for timber, firewood, or processed for dye.

The well-preserved tree lines on the north and east sides were identified in the field. Almost all houses have their entrance at the south side, and the tree lines were open because the wind from the south side is always gentle and cools the homestead in the summer. The tree lines at the west side are generally always cut to build a toilet, shower room, or kitchen when the owner needed to expand or improve the condition of their home. According to the Community Center Head of Hateruma Island, the local people believe that the east side is the place to welcome and send off a deity that descends into the home, because the sun rises from the east.

the Fukugi tree line　　tree line of the other tree species.

Figure 4: Distribution of trees surrounding the houses.

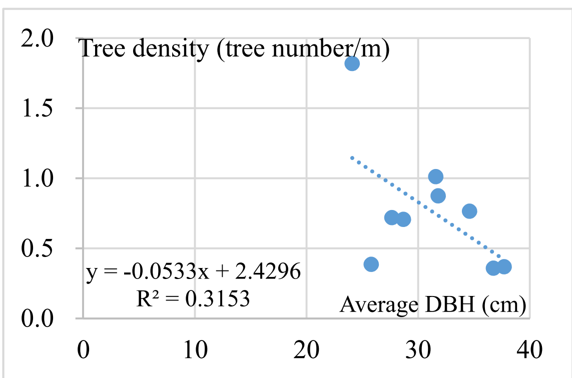


Figure 5: Correlation of DBH and tree density in the north side of the house (Hateruma Island)

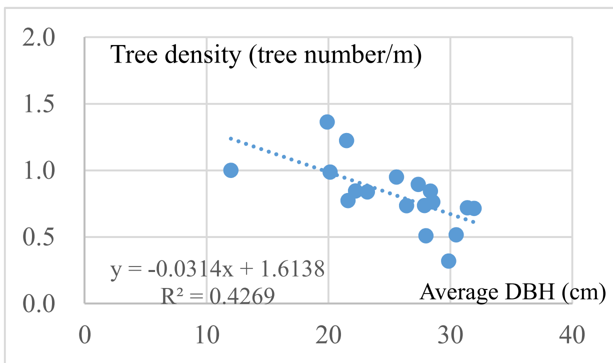


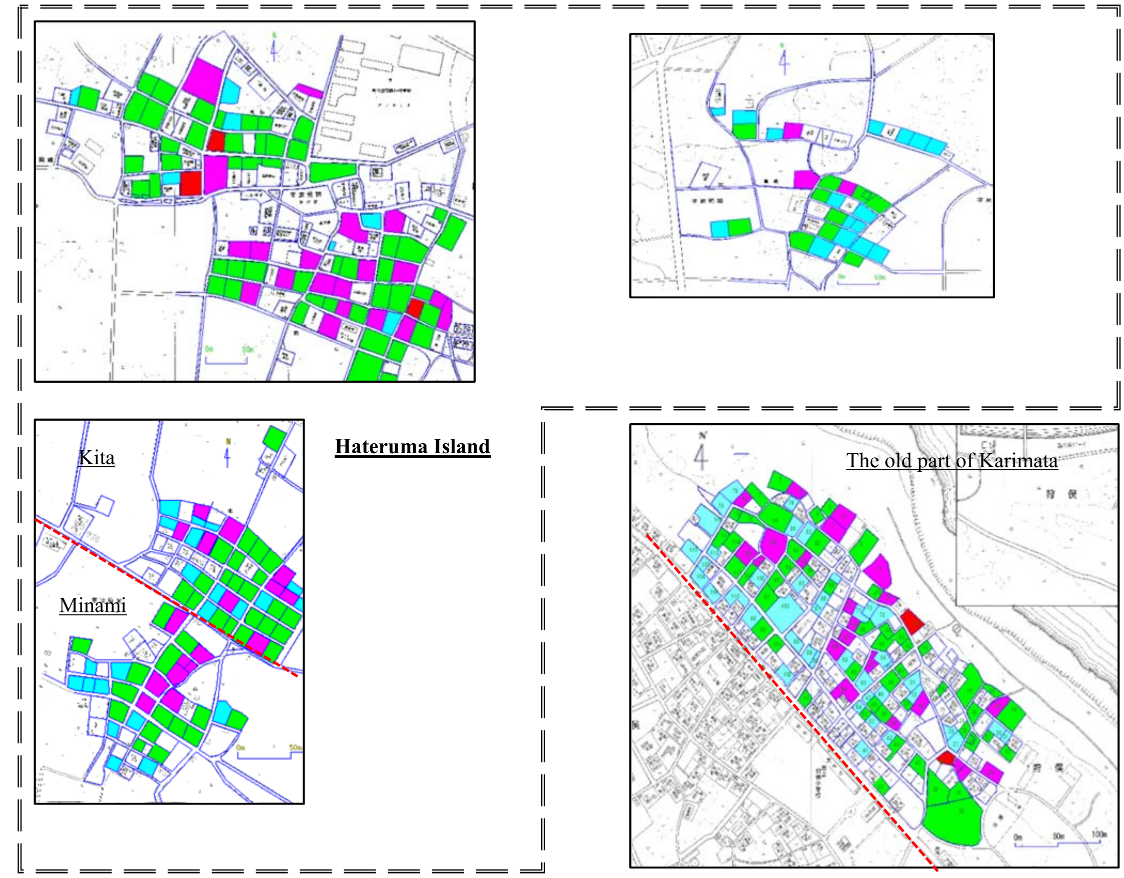
Figure 6: Correlation of DBH and tree density in the east side of the house (Hateruma Island)

In terms of the appropriate tree density, a total of 9 tree lines on the north side and 18 tree lines on the east side were identified in Hateruma Island and used to calculate. The average tree density[2)] was 0.8 ± 0.32 (SD) trees per meter. Moreover, a negative correlation between tree density and mean DBH size was found on both the east and north sides (Figures 5 and 6).

3.4 Spatial distribution of remnant Fukugi trees

There were three oldest trees, of which two were estimated to be more than 250-years-old on Hateruma Island and Karimata, respectively (Table 1). From Figure 7, we can see that trees older than 200 were primarily distributed in the four sub-hamlets of Hateruma Island.

In comparison with Hateruma Island, remnant Fukugi trees were much fewer at Karimata. Karimata Village is separated into two parts along Prefectural Road No. 230. The northeastern part is considered to be older and is covered with old Fukugi trees. Approximately half of the houses (115 of 200 houses) had tree belts that enclosed the homestead (Figure 7).



House having trees older than 250yrs
House having trees older than 200yrs
House having trees older than 150yrs
House having trees older than 100yrs

Figure 7: Spatial distribution of old Fukugi trees in the hamlets

3.5 Tree management

According to the local people, many Fukugi trees were cut down to improve transportation infrastructure and by the owner of the homestead. One resident (Mr. K., 60s, Hateruma Island) said that most of the trees at his house were cut when road expansion work began in the 1960s. They were required to cut seven trees on the east side and two trees on the south side, all of which were around 200-years-old, and give away part of their property for road construction. Since then, this resident has planted seeds along the roadside but the seeds hardly sprout.

Around the same time, some home owners cut all the trees around their houses in order to avoid having to remove fallen leaves and fruits. Clear cutting of all trees surrounding the house also took place on Hateruma and

Karimata Islands for similar reasons, because the owners were tired of removing dry leaves every day and the trees no longer provided a benefit. As a result, almost no trees are remaining at the center of the Kita sub-hamlet on Hateruma Island.

Regarding tree height management, several respondents said that a cautious attitude should be taken toward tree trimming. For example, Ms. Hayami (82-years-old) is very frustrated about treetop chopping. She said:

> *I requested that my sons chopped the treetop on the east side, and they shortened the trees by about 2–3 m 6-years-ago. After that, many branches sprouted and grew on all sides, but not straight up. When the typhoon season came, these branches were very weak. Therefore, I had to ask my daughters to cut these branches down this summer.*

Exposure to the island's strong winds seems to have restrained the trees from growing excessively tall. One resident (Mr. K., 60s) said that a Fukugi tree grows tall during its first 40 years, then the tree almost stops growing vertically, but the DBH becomes bigger and bigger. Some people are still worried that the highest part of the trees may be broken by strong winds and damage the roof of their homes.

Trees attacked by termites can be seen here and there. It was said that damage caused by past construction work and typhoons had fatally injured the old trees. These damaged trees develop hollows areas in their stems and are very vulnerable to future typhoons.

4 Conclusions

In total, 3,036 and 1,369 Fukugi trees of a minimum 5 cm DBH were measured in the villages of Hateruma and Karimata, respectively. The mean tree age was estimated at 112.8, and 92 years in Hateruma and Karimata, respectively.

The result that trees on the north side of the house are greater in number than the south and east is consistent with previous studies on Aguni Island (Ando et al. 2010a), and Imadomari in mainland Okinawa and Tonaki Island (Ando et al. 2010b). However, trees on the east side had the highest percentage, slightly less than those in the north, although we found that trees had been well-preserved on the east side of Hateruma Island to protect against strong typhoons. This suggests that wind direction, as well as surrounding topography, determines the actual distribution of trees. The topographical situation that the houses are located at the highest spot on this small isolated island in the Pacific Ocean has resulted in the adequate preservation of this windbreak.

The tree height was estimated at 7.2m, and 6.4m on average in Hateruma and Karimata, respectively. And it was found that the majority of the trees were between 6 and 10 m high. The tallest trees were found at an abandoned homestead.

In terms of tree dimension, differences were found among the isolated island and the village located on a relatively larger island. On the small island, trees reached a high density and were better managed to maintain an average height of 6–10 m. In addition, the average tree density was approximately 0.8/m for well-preserved tree belts.

Similar to the lessons from the other areas that the dynamic of old growth trees can be related to the biotic factors including diseases and abiotic factors such as air pollution (McCarroll and Loader 2004), the existence of these huge remnant trees on Okinawa islands also depends on natural and human factors. Exposure to typhoons and monsoonal winds are among the most important factors for the resident's remaining tree belts at their homestead. However, human factors are also important for tree cutting or conservation. The residents' awareness on tree conservation determines whether the trees were preserved or felled. Older generations generally have higher conservation awareness with regard to Fukugi trees, while younger generations are much less aware. These old growth trees have been managed and maintained by the villagers; however, the current conservation scheme has placed these old trees to face the threats of being clear-cut or abandoned with the socio-demographic transformation in the future. A new conservation network that includes the local government, urban residents, and volunteer groups is called for to conserve these old trees.

Note:

1) The local name of *Garcinia subelliptica* is Fukugi (Japanese:福木) in Okinawa, and its English name is common garcinia. Sometimes it is also literally translated as a "happiness tree". In a serial of *Garcinia subelliptica* tree research papers, we used its local name. Because it has been widely planted inside the villages of the Ryukyu Islands, and currently prevalently distributed on the islands.

Garcinia subellipitca tree is a significant tree species as windbreak for the coastal villages in Okinawa, in comparison; it is insignificant at the other places, such as the Philippines, Taiwan, and South China.

2) In this paper, we calculated the tree density in per meter of a tree line. Because almost all the trees were planted in a line as a belt at the border of the premise.

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