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Dimensions and Spatial Distribution of Remnant *Garcinia subelliptica* Tree Belts Surrounding Homesteads in a Coastal Village

- A Case Study of Shiraho Village, Okinawa Prefecture, Japan –

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Abstract: The aim of the present study was to compile an inventory of dimensions and spatial distribution of remnant old-growth Fuguki trees planted along the borderlines of homesteads as windbreaks hundreds of years ago in Shiraho village, Okinawa Prefecture, Japan. We measured 2,447 Fukugi trees with a diameter at breast height (DBH) of at least 5 cm. Mean tree height, DBH, and estimated tree age were 7.16 m, 24.3 cm, and 96 years, respectively. The total number of trees and tree dimensions were similar to those in our previously surveyed sites. However, approximately half of the surveyed trees were planted on the east sides of houses, probably to protect them from strong winds blowing from the Pacific Ocean in the east. A broad distribution of old trees in the village suggests that a proportion of the Fukugi trees may have been established long before and may have survived the Meiwa Tsunami in 1771.

Key words: coastal village, disaster prevention, homestead trees, old-growth trees, rural landscape

1 Introduction

Okinawa Prefecture, located in the southernmost part of the Japanese Archipelago, consists of 160 islands, including 41 inhabited and 119 uninhabited islands. Most of these islands are tiny and flat, and hence, vulnerable to natural disasters. In order to protect houses and farmland from strong winds in the coastal areas of Okinawa, tree belts were planted during the Ryukyu Kingdom Period (1429–1879), and have been maintained till this day. This landscape was constructed according to the Chinese *feng shui* concept, with *hougo*[1)] (抱護, embraced protection) as its key principle (Chen et al. 2008). Before the Second World War, coastal forests and homestead windbreaks were prevalent on the Ryukyu Islands. These trees, which were planted in the beginning of the Ryukyu Kingdom Period, can still be found widely distributed in the Ryukyuan villages (Chen and Nakama 2011a, b). However, a majority of the old trees/forests were destroyed by fire in WWII and by land development projects to consolidate fragmented farmland in the 1960s. In recent land consolidation projects, many windbreaks were destroyed to facilitate agricultural machine use and vehicular traffic. The old-growth trees of the traditional village landscape are rapidly vanishing, and it is vital to conserve them owing to their historical and cultural value.

The first step in our efforts to conserve old-growth trees in the Ryukyu Archipelago is to inventory the location and dimensions of the existing trees surrounding the houses. In previous surveys, we inventoried the remnant *Garcinia subelliptica* (Fukugi trees) on mainland Okinawa and a few small islands nearby (Chen and Nakama, 2011a; 2011c), and explored their cultural and historical significance; we did the same in several villages near the mainland of Okinawa, such as Bise and Imadomari in the north, Aguni Island, and the Tonaki Islands (Chen and Nakama 2011c). In the present study, we extended our survey of the dimensions and spatial distribution of remnant Fukugi trees to Shiraho village, Ishigaki Island, and its nearby tiny islands, with the aim to clarify the dimensions and distribution of remnant homestead trees on the isolated islands and coastal villages in the southernmost part of Okinawa Prefecture.

2 Survey sites and methodology

Shiraho village is situated at 124°14′24″E, 24°21′9″N, along the southeastern seaside of Ishigaki Island and is the third largest island in Okinawa Prefecture. Ishigaki Island belongs to Ishigaki City and functions as the business and transport center of the Yaeyama Island group. Ishigaki Island has an area of 229.94 km^2 and a population of 47,660, as of October, 2015 (Ishigaki City, 2016).

Shiraho village had a population of 1,565 in 728 households, as of December, 2014 (Ishigaki City, 2016). It was known as the “younger brother” of Miyara village

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to the west. The combined population of the two hamlets was 248 in 1661. Under modern Okinawa's *yosebyakushou*[1)] system, over 300 farmers emigrated from Hateruma Island to Shiraho village in 1713. Shiraho's population had grown to 1,574 in 1771, when a record 38-m high tsunami, the Meiwa Tsunami, killed 1,546 people, leaving only 28 survivors (Ishigaki City, first published in 1998, republished in 2013). Under *yosebyakushou*, 418 farmers emigrated from Hateruma Island to help rebuild Shiraho village after the Meiwa Tsunami. The population of Miyara village was 1,221 before the tsunami, but 1,050 lives were lost in the same event. A total of 320 *yosebyakushou* moved from Kohama Island to help the 171 farmers rebuild Miyara village (*ibid*.).

We selected Shiraho village as our survey site because of two factors: the well-preserved Fukugi tree belts and the impact of Meiwa Tsunami on the village landscape. We trained seven local volunteers to assist in data collection in Shiraho village. The survey was conducted during October and November 2016.

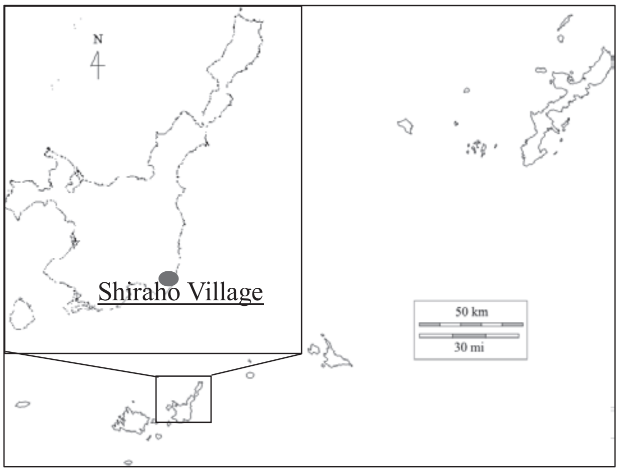

Figure 1: Location of Shiraho village

We measured and examined trees following the methods of Chen et al. (2016). Field surveys were conducted to record the following characteristics of each tree: diameter at breast height (DBH; measured at a height of 1.3 m), height, and cardinal direction relative to the nearest homestead. All Fukugi trees in the village with a DBH larger than 5 cm were surveyed. Tree age was estimated based on DBH. All Fukugi trees with a DBH greater than 25 cm were estimated to be approximately 100 years old, and were considered to have been planted during the Ryukyu Kingdom Period (Chen and Nakama, 2011c). There are two methods for estimating the age of Fukugi trees: by equation (1) proposed by Hirata (2006), and by 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 1.3 m above ground, and x_2 is the diameter (cm) at approximately 0.2–0.3 m above ground. We adopted the original Hirata method (equation 1), since we only measured DBH in the field. Considering a possible deviation in the tree's estimated age from its real age, age classes (of 50 years) were used for the analyses.

The location of Fukugi trees of DBH > 5 cm in all surveyed houses was recorded on a residential map (Zenrin Co., LTD., Fukuoka, Japan).

Surveyed trees were classified into five groups according to their estimated ages: 100–149 years, 150–199 years, 200–249 years, 250–300 years, and over 300 years. The tree age-based distribution was mapped with respect to houses (Figure 5). The spatial distribution of the oldest Fukugi trees within each property was also mapped. We assumed that house owners selectively cut Fukugi trees for specific purposes, such as timber, and some trees may have died due to the damage caused by strong typhoons. However, in order to maintain windbreaks, the locals did not cut down all the trees at once. This selective cutting allowed the oldest trees to survive, thereby providing historical data regarding residential land evolution. Additionally, tree belts of other species were also noted and mapped to provide with information related to tree species selection. Survey data were analyzed using SPSS software (v. 24).

3 Results and discussion

3.1 DBH and tree height

A total of 2,447 Fukugi trees were measured in Shiraho village; most were < 12 m high and < 200 years old (Figure 2). The mean and median tree heights were 7.16 m and 7.21 m (Table 1), the mean and median DBH were 24.3 cm and 24 cm, and the mean and median tree ages were estimated to be 97 and 96 years, respectively. The smallest 5 % of the surveyed Fukugi trees were < 3 m tall, with < 5.6 cm DBH, and were < 22.4 years old; the largest 25 % were > 9.10 m tall, with > 33.5 cm DBH, and were > 134 years old.

Shiraho village had more remaining trees than most of the previous survey sites (Chen and Nakama, 2011c).

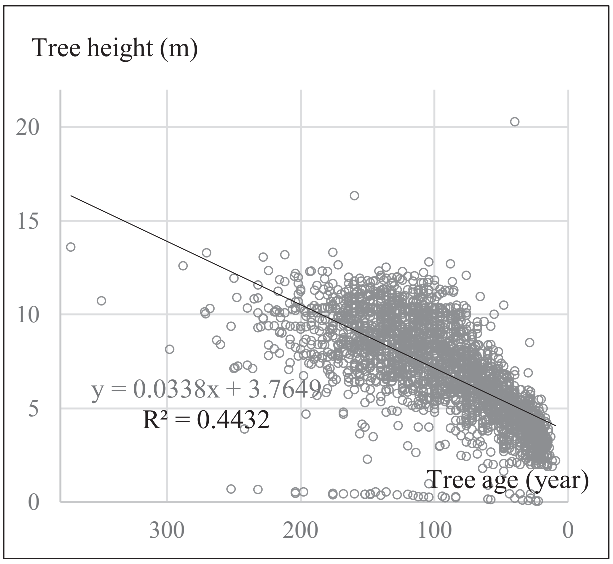

Figure 2: Distribution of tree age and tree height in Shiraho village

Table 1 Summary of the dimensions of Fukugi trees in Shiraho village

		Tree height (m)	DBH (cm)	Tree age (years)
Tree number	Valid	2447	2441	2441
	Missing	4	10	10
Mean		7.16	24.3	97.1
Median		7.21	24.0	96.0
Std. Deviation		2.53	13.1	52.4
Minimum		0.90	2.0	9.2
Maximum		20.30	93.0	372.0
Percentiles	5	3.00	5.6	22.4
	25	5.20	13.4	53.4
	50	7.21	24.0	96.0
	75	9.10	33.5	134.0

There was little difference in mean height, mean DBH, and mean age of trees, between Shiraho and other previous survey sites, e.g., Hateruma Island (Chen et al., 2016). The tallest trees in Shiraho (5–25 percentile) were taller than those in Hateruma. Mean DBH and estimated ages were greater for trees in Hateruma.

The largest tree in Shiraho village had a DBH of 93 cm and was estimated to be approximately 372 years old. This old tree in Shiraho was comparable to the largest Fukugi tree found in Okinawa Prefecture, which was 15 m tall with a DBH 93.3 cm and grew on the small island of Hamahiga (Chen and Nakama, 2011b), an island connected to the east of mainland Okinawa by a long bridge.

3.2 Cardinal directions of tree stands

Cardinal directions of trees, relative to the houses, were also recorded (Figure 3). The four directions were approximated, and north does not necessarily refer to geographical north in this study. Approximately 95 % of the trees were categorized as being on the north, south, east, or west sides of each homestead. Out of the remaining 5 %, most were at the corners, and only a few were at the center of house plots, hence categorized as “Other”.

Approximately half of Fukugi trees (42.4 %) were planted on the east side of houses, while 29.9 % were planted on the north side (Figure 3). In contrast, Fukugi trees on the west side had the lowest occurrence (10.6 %), followed by those in the south (12.5 %). The remaining 4.6% of the trees were surveyed in the corners of the residence.

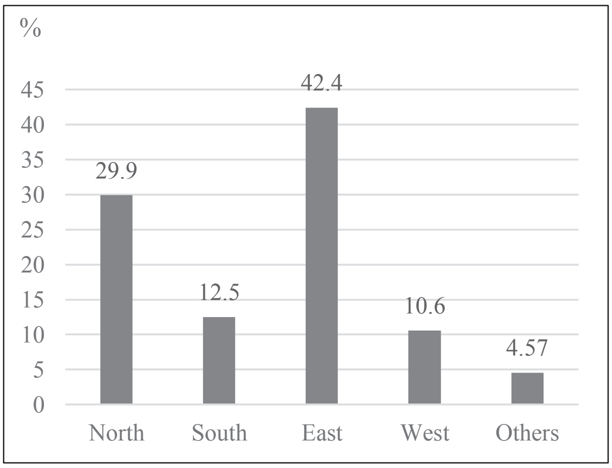

Figure 3: Fukugi tree distribution by cardinal direction relative to house plots.

Note: “Other” refers to trees at the center or corners of house plots.

The trend of planting a dense tree belt along the east and north sides of the houses is consistent with that reported in previous studies on Aguni Island (Ando et al. 2010a), Imadomari on mainland Okinawa, Tonaki Island (Ando et al. 2010b), Hateruma Island, and Karimata on Miyako Island (Chen et al., 2016). As Shiraho village faces the Pacific Ocean to the east, Fukugi trees must have been deliberately planted and maintained facing east to protect houses from devastating typhoons. However, several previous studies on mainland Okinawa and its nearby isolated islands had reported that Fukugi trees were most densely planted facing north (Ando and Ono, 2008; Ando et al., 2010a; Ando et al., 2010b).

3.3 Tree belt coverage and tree age distribution

Tree belts were usually longer along the eastern side of houses than on the western side (Figure 4). In particular, houses in the southwest part of the village had few tree lines.

In addition to Fukugi trees, other plant species were also used as windbreaks (Figure 4), among which *Diospyros egbert-walkeri* was the most common, while *Podocarpus macrophyllus* and *Calophyllum inophyllum,* were also planted. *Diospyros egbert-walkeri* and *Podocarpus macrophyllus* are small- to medium-sized evergreen tree species that were often found in the center of the village. *Calophyllum inophyllum,* a large evergreen tree, was found planted in house plots, near the beach, at the eastern side of the village.

In general, we found that the two largest trees were present in the north and central part of the village, very close to the sacred site of *Kadekaru on*[3)], which is considered the geographical and spiritual center of the village (Figure 5). Moreover, Fukugi trees estimated to be older than 250 years were distributed in the central part of the village, and small Fukugi trees were found more often at the outskirts of the village.

The finding that older trees were distributed in the center of the village is consistent with those of several previous studies (Chen et al., 2005; Chen et al., 2006; Chen and Nakama, 2011c), implying that new houses were built on the periphery of the village.

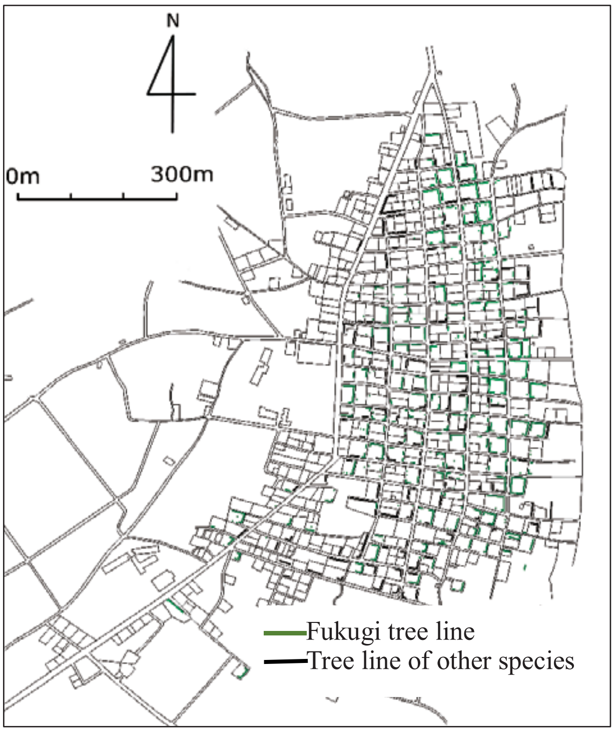

Figure 4: Distribution of trees surrounding the houses

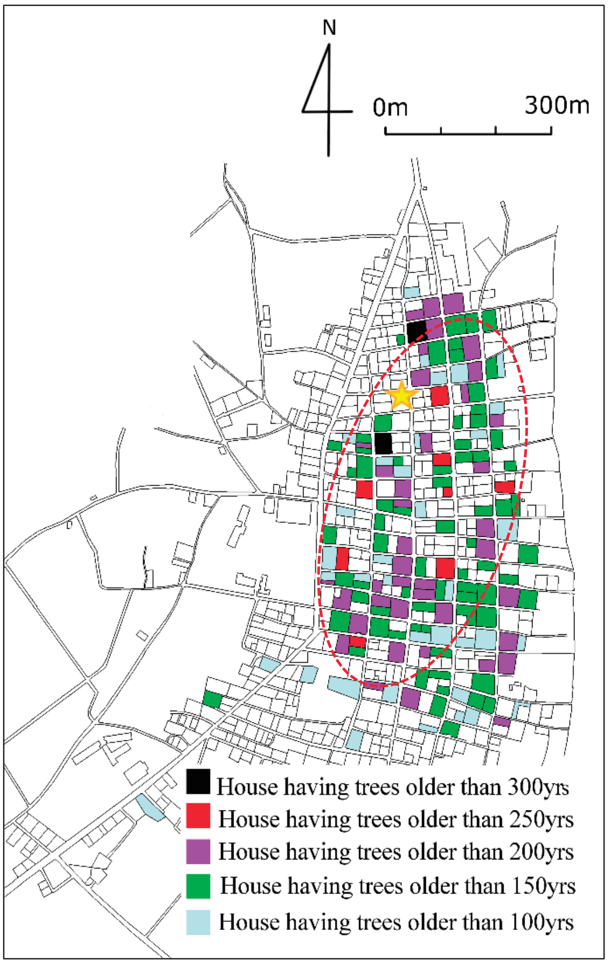

Figure 5: Spatial distribution of old Fukugi trees in Shiraho village

★Sacred site of *Kadekaru on*: considered to be the center of the village.

3.4 Fukugi tree plantation age and village relocation after the Meiwa Tsunami in 1771

Shiraho village has relocated twice after the Meiwa Tsunami in 1771, which was the largest event since 1644 till date.

The tsunami had struck the southern Ryukyu Islands (Miyako-Yaeyama Islands), and based on reliable historical documents, the run-up heights were estimated up to 25 m in Shiraho village, and 32 m in Miyara village, along the southeastern part of Ishigaki Island (Goto et al., 2012, Kawana, 2003). The tsunami in 1771 killed a large number of village people, destroyed most of the houses, and caused tremendous damage to farmland in and around the villages on the east coast of Ishigaki Island, including Shiraho village (Ishigaki City, first published in 1998 and republished in 2013).

After the tsunami, Shiraho moved to a highland to the north of the original village site. However, the villagers moved back eventually to rebuild their houses near the original village site after 10 years. The clustering of village houses, centered on the sacred site of *utaki*, is an important characteristic of pre-modern villages in the Yaeyama district. Therefore, it was assumed that village people chose to live close to the coast, despite the destructive tsunami, for two reasons: a strong community feeling and the benefits of enclosed protection from forest belts (Tokunou, 2012).

Several studies (e.g., Ishigaki City, 1998) have shown that while everything collapsed after the tsunami, the flat land remained covered with stones after the catastrophe. However, our survey of remnant Fukugi trees suggested that the number of large Fukugi trees with an estimated age beyond 250 years in Shiraho village was comparable to that in Hateruma, (Table 2). In Shiraho village, we found 66 trees older than 200 years, 12 older than 250 years, and 2 were over 300 years. Considering that there were 14 old trees distributed among 10 houses (Figure 5) and that people returned to rebuild their original village soon after the tsunami, it may be assumed that a proportion of the older Fukugi trees must have survived after the tsunami.

Table 2: Descriptive data about Fukugi trees by estimated age (year) in Shiraho village

Total number	Number of trees by estimated age (years)						
	0-50	51-100	101-150	151-200	201-250	251-300	301-
2441	561 (23.0)	714(29.3)	770 (31.5)	316 (12.9)	66 (2.9)	12 (0.5)	2 (0.1)

Note: Number in ( ) represents the percentage

4 Conclusions

A total of 2,447 Fukugi trees with a minimum DBH of 5 cm were examined in Shiraho village. The mean tree height, DBH size, and estimated tree age were 7.16 m, 24.3 cm, and 96 years, respectively. The three dimensions of Fukugi trees did not differ much from the trees previously surveyed.

Over 70 % of the surveyed Fukugi trees were present at the eastern and northern sides of the homesteads. Approximately half of the surveyed trees were in the east, suggesting that the trees were meant to protect the houses against typhoons.

Fourteen remnant Fukugi trees, estimated to be > 250 years old, were widely distributed in the village, suggesting that a proportion of the old Fukugi trees may have survived the tsunami in 1771. Nevertheless, it is obvious that closely planted Fukugi trees could not effectively protect villagers or houses, as the run up height of the tsunami was more than 30 m. However, these remnant old-growth Fukugi trees implied that unlike other tree species, Fukugi trees may survive even after the catastrophe of a devastating tsunami.

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Note:

1) *hougo* is the English transliteration of the Japanese character 抱護, which literally translates to 'embraced protection.' *Hougo* is a key concept of Ryukyu Feng shui, which refers to an enclosed configuration, ensuring a desirable space for achieving good fortune. According to the old documents, this enclosed configuration can be achieved using the topography of the surrounding hills and planted trees/forests.
2) *Yosebyakushou* is a compulsory system of immigration of a farming population to villages where this population has dropped drastically.
3) *Kadekaru on* is a sacred site of *utaki*, which is the center of the Harvest Festival held every year. *Kadekaru on* has been displaced several times in the past, and moved to the current site in 1953.

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