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The State of Conservation and Management of Old *Garcinia Subelliptica* Trees: A Case Study in Aguni Island, Okinawa Prefecture

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Abstract: Fukugi (*Garcinia subelliptica*) tree lines were planted along the periphery of properties shaping a green landscape on the islands of the Okinawa Prefecture. Throughout the years, these trees have provided diverse ecosystem services, including wind breaking, home cooling, and air purification. However, in recent decades the trees vanished at a fast pace mainly due to human action. This study aimed at clarifying the present distribution of remnant Fukugi trees and evaluating their habitat and health condition in order to establish conservation and management strategies. A total of 3,052 trees, estimated to be over 100 years old, were found in the three hamlets of Aguni Island: Higashi, Nishi, and Hama. Diameter at breast height, tree height, and orientation were measured and tallied for each tree in 2009. In addition to natural hazards such as typhoons, human activities largely degraded tree habitat and health. Life style changes and population loss in the rural areas are among the major reasons contributing to the decrease of Fukugi trees. Private ownership of woodlands is considered a major limitation to restrict the cutting of old trees. Increasing environmental awareness through the education of village inhabitants will be effective for protecting the old trees and conserving the landscape.

Key words: coastal village, heritage tree, homestead woodland, old tree conservation

1 Introduction

With the growth of global population and rapid urbanization, the natural ecosystem within and around human settlements is fast degrading and facing land use competition from man-made structures. In contrast, people need to escape from the cities to the surrounding countryside with natural sceneries to have peaceful minds. Urban forestry has been widely studied for its ecological services irrespective of forest area (Roy *et al*., 2012). The benefits provided by urban trees to human populations are diverse, including microclimate regulation through the reduction of wind speed, solar radiation, and storm water runoff, and minimizing flooding damage (Miller, 1997; Low *et al*., 2005; Burden, 2006). Being the main urban landscaping factor, urban trees are also under severe abiotic and biotic pressures. Environmental and management problems concerning their existence, such as reduced solar access, and dropped branches, leaves, flowers, and seeds, have been reported.

Trees also play a significant role in providing ecosystem services in coastal settlements. For example, a single species of Fukugi tree (*Garcinia subelliptica*) has shaped a specific settlement landscape in Okinawa, raising the interest among national researchers concerning architecture (Ando *et al*., 2010), landscape ecology (Chen *et al*., 2014), and human geography (Chen and Nakama, 2011). These previous studies examined the spatial distribution of existing trees and the potential of applying such distribution in future urban landscapes (Ando *et al.,* 2010). Fukugi trees, particularly old ones, should be studied in their historical, cultural, and ecological context, and should be treated as a natural and cultural heritage.

Tree habitat conditions and related conservation policies have not been systematically studied. Here, we examine the current conservation state of old Fukugi trees at the local level, exploring conservation models and experiences from conserving the traditional trees in coastal areas. Moreover, knowledge of remnant old trees is still scarce, despite of its cultural, historic and ecological significance. For example, Ando *et al*. (2010) only measured two of the three hamlets in Aguni Island. Since Fukugi trees, in particular old trees, are degrading due to natural and human factors, such as typhoons, diseases, and tree cutting, the measuring and registering of all old trees is of extreme importance to acquire the basic data for environmental education and local conservation strategies.

2 Survey site and methodology

Aguni Island (Figure 1) is a tiny triangular island (12 km diameter), about 57 km northwest of Naha, Okinawa (26° 34′ N, 127° 13′ E), with a total area of 7.64 km^2 (Figure 2). The central and southern parts of the island are mainly composed of Ryukyu limestone, which is coral limestone formed during the Pleistocene; lava is found on the west of the island. Island surface soils are mainly Shimajiri Mahji (dark red soil or Ryukyu limestone, neutral to weakly acidic), except for a small area of Kunigami Mahji (red and yellow soil or other stone soil, strongly acidic). Recently formed coral reef surrounds the island. The island is short of fresh water resources.

As of September 2015, the island had estimated population of 758 people, accounted for 442 households. There are currently three villages in Aguni Island: Higashi, Nishi, and Hama, with a population of 181, 318, and 259 individuals, respectively (Aguni Village, 2015). Higashi and Nishi hamlets are located at the center of the island, and Hama is near the coast. Higashi and Nishi are adjoining hamlets and

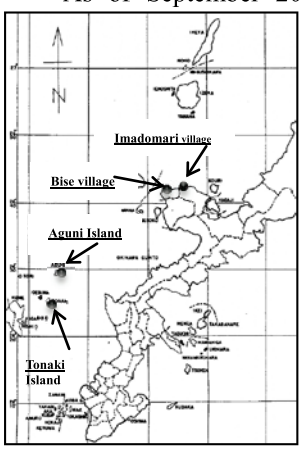

Figure 1: Location of Aguni Island

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were not separated until 1872 (Aguni Son Shi, 1984); they were named Yae, also called Agi (meaning "inland") in contrast to Hama (meaning "seashore"). Aerial photos of the three hamlets are shown in Figure 2. Archaeological studies revealed that ancient people lived on the high mesa near the coast, on the western part of the island where the sea was easily accessible, forming a gathering and hunting society (Aguni Son Shi, 1984). People moved to the flat lowlands only several hundreds of years ago reclaiming the agricultural lands nearby; sugar cane and sweet potato are widely planted. For working reasons, a large number of villagers moved to Naha, the capital city of Okinawa Prefecture, before World War II, and population loss is still increasing.

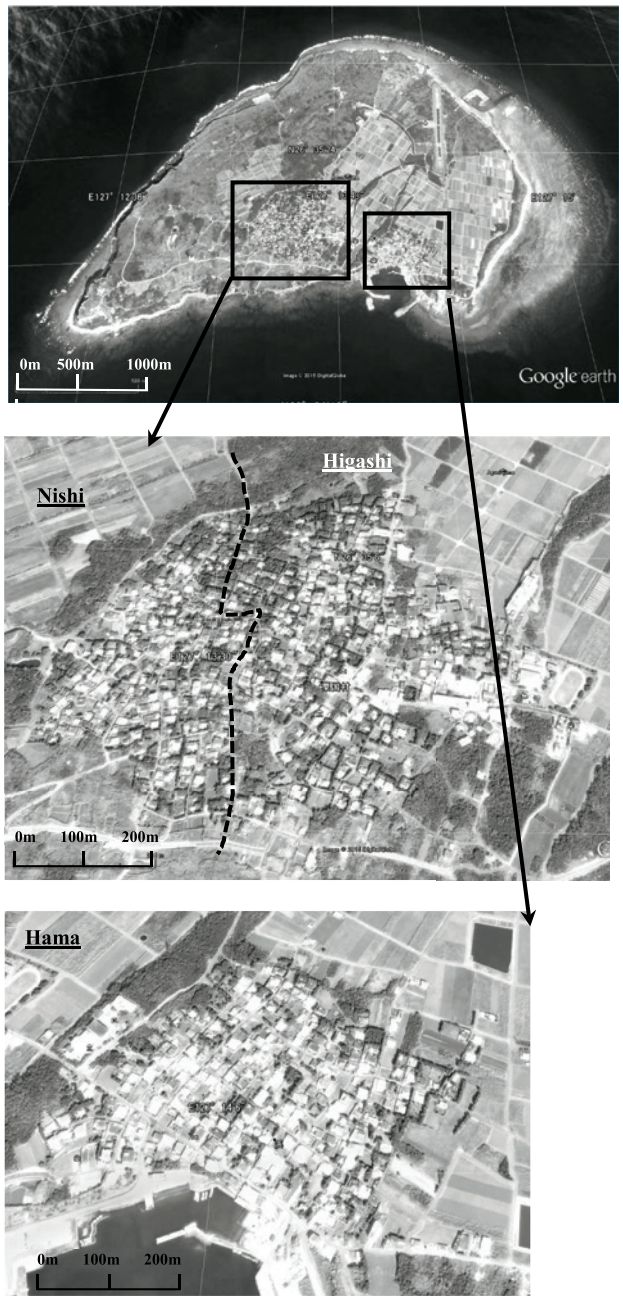

Figure 2: Aerial photos of three survey hamlets
Data source: Google earth

A combination of tree measurements in the field and interviews with the local population was used in this study. Field surveys were conducted in April 2009 to obtain the following characteristics for each tree: diameter at breast height (DBH), height, and orientation within each village. Interviews with village leaders and influential people were conducted in April 2015 to collect information on tree management and conservation. The habitat and health condition of trees older than 250 years was evaluated in June 2015.

Only the old Fukugi trees in the villages were surveyed, and DBH was determined at a height of 1.3 m; the total tree height was also measured and recorded. All Fukugi trees with DBHs larger than 25 cm were estimated to be around 100 years old, and were considered to have been planted during the Ryukyu Kingdom Period (1429–1879) (Chen and Nakama, 2011). 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.

Because our field survey only measured DBHs at 1.3 m above ground, we adopted the original Hirata method. However, this approach has some limitations. First, it is based on the measurements taken from two cut stumps located in the southern part of Okinawa Island. Second, other factors besides tree age, *e.g.*, site, climatic conditions, and competition, affect annual ring width. Thus, the tree ages calculated in the present study are approximate, not accurate values. Further, considering possible deviation of the tree's estimated age toward the tree's real age, age classes of 50 years were used in the analyses.

All surveyed houses with Fukugi trees were indicated on a residential map published by Zenrin, a large company specializing in Japanese residential maps. The four age groups were mapped by house and presented in different colors. The habitat, artificial constraints to growth, and health condition were evaluated during the field surveys conducted in June 2015 for trees with more than 250 years (age data obtained in the 2009 surveys).

In addition, influential people, the leader of the village, and the staff from the village tourism office were interviewed to collect information on traditions, changes, problems, and challenges regarding old tree protection and tree landscape conservation and their potential use.

3 Results and discussion

3.1 Tree age and tree height

A total of 3,052 trees had a DBH over 25 cm: 1,760 were found in Higashi, 752 in Nishi, and 540 in Hama. This difference in numbers was partly due to the total residence area (Table 1) and to the density of tree lines.

Table 1: Descriptive Statistics of old tree height by hamlet

Hamlet	Item	N	Mini	Maxi	Mean	SD
Higashi	Tree height (m)	1760	0.66	11.60	7.19	1.7
	DBH (cm)	1756	25.0	74.0	33.1	7.6
	Estimated tree age (year)	1756	100	296	132	30.3
Nishi	Tree height (m)	752	2.10	13.08	7.10	1.8
	DBH (cm)	751	25.0	65.2	33.4	7.3
	Estimated tree age (year)	751	100	261	133	29.1
Hama	Tree height (m)	540	2.10	13.0	6.98	2.0
	DBH (cm)	540	25.0	70.3	31.3	6.5
	Estimated tree age (year)	540	100	281	125	26.1

Table 2: The Number of Remnant Fukugi trees in selected villages

Village	Area of Village Houses(m^2)[*1]	Number of Remnant Fukugi Trees						Estimated age of Biggest tree	Mean Tree Height (m)
		Total	≧300 yrs	250～299 yrs	200～249 rs	150～199 yrs	100～149yrs		
Bise	191,143	1,075	1	17	89	360	609	300	9.94[*2]
Tonaki	134,723	964	0	2	9	111	842	268	8.42[*2]
Imadomari	263,378	1,293	0	15	85	307	886	294	9.00
Higashi	233,556	1756	0	14	55	321	568	296	7.19
Nishi	127,567	751	0	2	26	155	1366	261	7.10
Hama	137,602	540	0	3	6	65	466	281	6.98

[*1]:The areas of all village houses is a rough value calculated based on the residential map published by ZENRIN. The area number only include the houses which were assumed to have been built about 100 yrs earlier.
[*2]: Mean tree heights in Bise and Tonaki was counted based on the survey data from 2005-2008.

Table 3: Distribution of big Fukugi trees by the side of the house courtyard

Village	Surveyed house number	Total number of Fukugi≧25cm (DBH)	East[2)]		West		South		North	
			N	%[3)]	N	%	N	%	N	%
Bise[1)]	99	1075	–	–	–	–	–	–	–	–
Tonaki	165	918	276	30.10	157	17.10	174	19.00	311	33.90
Imadomari	155	1293	299	23.10	323	25.00	278	21.50	393	30.40
Higashi	204	1764	485	12.81	197	11.17	239	13.55	847	48.02
Nishi	129	752	232	6.57	101	13.43	116	15.43	303	40.29
Hama	85	541	184	34.00	59	10.90	85	15.70	213	39.40

Note: [1)] Data of Bise were surveyed with the help of students in the lab in the summer of 2008. The tree stand by the side was not recorded.
[2)] The tree number was classified into the different direction of the house coutyard.
[3)] Refers to the rate of tree number founded in one direction to the total surveyed Fukugi trees inside the village.

However, human factors, such as environmental consciousness and perception, must also have had some effect as the three villages were under similar geographical influences.

The largest tree was measured in Higashi (DBH = 74.0 cm) and was estimated to be 296 years old. The largest trees in Nishi and Hama had DBHs of 65.2 cm and 70.3 cm and were estimated to be 261 and 281 years old, respectively, therefore, being younger than the one in Higashi. The mean DBHs were 33.1 cm (S.D. = 7.6 cm) in Higashi, 33.4 cm (S.D. = 7.3 cm) in Nishi, and 31.4 cm (S.D. = 6.5 cm) in Hama, with corresponding estimated average ages of 132, 133, and 125 years.

Mean tree height was 7.19 m (S.D. = 1.7 m), 7.10 m (S.D. = 1.9 m), and 6.98 m (S.D. = 2.0 m) in Higashi, Nishi, and Hama, respectively. The tallest trees measured in each hamlet were about 11.6 m in Higashi and 13.08 m in Nishi and Hama; the smallest trees were 0.66 m in Higashi and 2.10 m in Nishi and Hama.

Old Fukugi trees on Aguni Island were pruned and

growth-controlled at lower heights than in previously surveyed sites (see Table 2). The majority of old trees had heights between 5 and 9 m in Higashi and between 4 and 10 m in Nishi and Hama, whereas those in the villages of Bise and Imadomari in Mainland Okinawa were about 10 and 9 m, respectively. The reduced tree height observed in Aguni Island can be partly explained by folklore. The head of local tourism organization in Aguni Village, Mr. T. (male, around 60 years old), explained that locals dislike tall trees because crows usually perch on the branches of such trees announcing that someone is going to die, in the direction toward which the crow is cawing; hence, neighbors ask the owners of such tall trees to chop them at a low level.

3.2 Spatial distribution by house

The spatial distribution of the highest Fukugi tree within each property was mapped in Figure 3. We assume house owners selectively cut Fukugi trees for a special purpose. In the history of the Ryukyu Kingdom, there was a shortage of timber in isolated islands. As there is no forest in Aguni Island, Fukugi trees must have been important as the timber resource for building houses. However, the locals did not clear-cut all the trees in a line in order to maintain their windbreak function, allowing the oldest trees to survive until now and providing historical data concerning residential land evolution. In this study, trees older than 200 years were mostly found in the center of the Higashi village (Figure 2), which is consistent with this being the oldest part of the residential area within the hamlet.

Tree positioning (east, west, south, and north) was recorded considering the house as the center of the property in order to reveal the owner's preference for tree planting and management. As shown in Table 3, the percentage of old trees found north of the house was about 48% in Higashi, 40% in Nishi, and 39.4% in Hama. These results are consistent with previous surveys conducted in the Okinawa Prefecture, revealing that remnant old Fukugi trees were mostly distributed at the north of the houses, to prevent the strong winter winds from reaching the houses (Ando *et al*., 2010; Chen and Nakama, 2010).

Figure 3: Spatial distribution of old Fukugi trees in the hamlets of Higashi, Nishi and Hama

3.3 Tree condition and performance

Nineteen trees examined in the 2009 survey had over 250 years old, and therefore, were evaluated for tree dimension, habitat, and health condition (Table 4). Approximately half of these trees were degraded to some degree: a) one tree had vanished, probably because it was cut down; b) four trees were in fatal decline showing hollow trunks. The village leader informed us that half the trunks and branches were destroyed by a typhoon and that the remaining half trunks were dangerous and should be cut down; and c) four other trees were also in decline with partly dried-up leaves due to the former huge typhoons that hit the island blowing sea water into the villages, even into those that were quite far away from the seashore, and damaging the leaves.

Photo 1: Coastal village with Fukugi tree lines and coral stone fence on Aguni Island

In addition to the natural hazards, human activities largely degraded tree habitat and health. In particular, during the 1960s, all village roads were widened and

Table 4: Dimensions and evaluation of the oldest 18 trees on Aguni Island

DBH (cm)	Estimated tree age	Tree height (m)	Crown diameter (m)	Health condition
65.2	261	6.45	4.7	Partly dried-up leaves
65.3	261	6.15	2.0	Half degraded
68.0	272	8.02	4.1	Healthy
65.6	262	7.43	3.2	Healthy
67.0	268	9.35	6.3	Partly dried-up leaves
63.0	252	5.88	1.9	Hollow trunk
68.1	272	7.43	2.8	Hollow trunk
68.8	275	8.2	3.8	Hollow trunk
63.8	255	5.77	3.7	Healthy
64.9	260	10.35	4.7	Slightly degraded
65.5	262	10.05	7.1	Partly dried-up leaves
62.4	250	9.38	5.5	Healthy
70.8	283	6.85	6.1	Healthy
74.4	298	10.78	3.5	Partly dried-up leaves
69.8	279	10.03	4.0	Healthy
64.7	259	5.44	2.5	Hollow trunk
60.6	242	5.95	3.6	Healthy

covered with concrete to ensure smooth movement of cars. In the other villages, stone fences and tree lines were moved inside properties to avoid their elimination (or cut in the case of trees) due to road construction. Thus, we can still see a landscape of trees bordered by a coral stone fence on the island (photo 1). Among the remaining 18 trees, 16 were standing along concrete roads and two were at the boundary of two houses, with their roots and lower part of the trunks covered and enclosed within stone fences standing only 20 cm away from the trunk; the lower trunks of the 16 trees were also trapped inside stone fences. Direct injuries were also found in the old trees. Because the roots were tightly covered with concrete, trees could not perform vital cycles properly and tree leaves became yellowish. Some people also used hollow tree trunks to put garbage and burn it.

3.4 Tree care and protection

According to the village leader, about 50 years ago the pupils were organized to remove the fallen tree leaves from the road. These, together with the fallen leaves inside properties were used as important green manure for home gardens and fields. Nowadays, the youth's association performs pruning at the beginning of October, according to the Lunar Calendar. The interviewees stated that regulating old Fukugi trees pruning is somewhat difficult because the trees are in private properties, and no regulation or decree restricts their cutting. The Mayor of Aguni, Mr. S. (male, 62 years old), said:

> *People cut all the trees in the residential land where they plan to build a new house. Without any restrictions, tree numbers will decrease. However, it would be very difficult to regulate tree cutting, as the trees are privately owned. Regarding tree pruning, the major problem concerns trees in empty houses. These trees were abandoned without proper maintenance but it is impossible to enter someone's property and prune the trees, even if the budget allows it.*

The Mayor was born on the island and has been living there ever since, showing a great attachment toward the trees. According to him, treetops should not be cut as this degrades tree condition. He also conceived the idea of repairing an old house surrounded by old Fukugi trees and opening it to the tourists; walking route along the tree lines will be used as tourist attractiveness and, in turn, this would raise conservation awareness amongst the village inhabitants.

The lacking of knowledge concerning the history and cultural significance of Fukugi trees is the main reason for neglecting trees care in Aguni Island. As trees have not been grown in recent decades, all standing trees must be planted around 100 years ago and younger trees must have been naturally generated from fallen fruits. The village deputy, Mr. I. (male, 62 years old) said:

> *Because Fukugi trees are commonly found throughout the island no one thinks that they are important. People wanted to use as much land as possible to build houses and thus the tree lines and stone fences were removed. Hama had Fukugi tree lines on almost every property, but the majority of trees was cut when people replaced the traditional stone fences for concrete fences. In addition, I have never heard that someone planted new tree lines along its property. Having to remove fallen leaves and the bad smell of decayed fruits are two major negative perceptions for the owners. We enjoy tree landscapes if we do not have to take the responsibility of tree maintenance. Hence, it is difficult to persuade people to engage in tree conservation.*

When asked for their opinion concerning the link between Fukugi trees conservation and tourism development, the informants mostly agreed that tourism development is a good opportunity for tree conservation. Mr. T. (male, about 60 years old) from the local tourism organization of Aguni Village responded that the conservation and proper management of Fukugi tree lines is not only important as a tourist attraction but also for improving the local environment. Mr. Toguchi also mentioned that tourists recognize they are comforted and healed by the combination of flourishing trees and stone fences along walking paths in rural environments.

4 Conclusion and management implications

Trees are an important element in an urban/peri-urban

settlement landscape. Houses can be rebuilt, but trees, in particular old trees, are sensitive to the environment and subject to irreversible damages (Jim 2004). On the islands of Okinawa, tens of thousands of trees have been planted to provide humans a safer and more productive environment, but many have vanished due to rapid urbanization. In addition to natural hazards, *e.g.*, typhoons, human activities have largely degraded tree habitat and health. Life style changes and population loss in the rural areas are among the major reasons contributing to decrease in the number of Fukugi trees.

Private ownership of woodlands is considered the major limitation to restrict old trees cutting. Trees are chopped, pruned, and maintained at low heights within private properties at the owners' will and responsibility. Increasing environmental awareness through education programs directed at village inhabitants might be the most effective way to protect old trees and conserve the landscape.

Management measures are urgently needed to protect the remnant trees from threats. The local government agrees that they should have played a more important role in tree management and conservation, but also recognizes that this is difficult, as most trees are in private properties. The lessons learnt from Aguni Island's experience should alert scientists about the low awareness of the residents and local administrative staff toward these small and fragmented woodlands, which have much higher ecological significance than their tangible economic values.

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