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Key Ecological and Cultural Characteristics of Homestead Windbreak Forest Landscapes in Okinawa, Japan

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Abstract: This study investigates the Fukugi (*Garcinia subelliptica*) windbreak landscapes on Iriomote Island through case studies in two of its oldest villages, Sonai and Hoshitate. These windbreak forests, integral to the cultural landscape of Okinawa, offer both ecological and socio-economic benefits. Using field measurements and surveys, the research analyzes the distribution, growth patterns, and historical significance of Fukugi groves within the village setting and compares naturally regenerated forests with those planted by humans. The findings underscore the importance of Fukugi trees in promoting sustainable rural landscapes, where they dominate the local ecosystem of rural settlements. Fukugi windbreak landscapes in Okinawa are characterized by trees encircling homes on all four sides, distinguishing them from homestead windbreaks found in other regions of Japan. Surveys from the two villages suggest that the original homestead windbreak forests in the Yaeyama region contain a diverse mix of tree species, with Fukugi and *Calophyllum inophyllum* being predominant, along with other useful species like *Diospyros ferrea* and *Podocarpus macrophyllus*. These species were selected not only for their windbreak capabilities but also for timber and home furniture production. The study's findings on naturally regenerated Fukugi groups support the hypothesis that the cultivation of Fukugi as a windbreak species originated in the Yaeyama region and likely spread to other parts of Okinawa, influencing both the ecological and cultural evolution of the region's landscapes.

Keywords: cultural issues; community forests; human dimensions of forests; Japanese forestry; Iriomote Island; non-timber forest products; traditional Okinawan landscapes; traditional ecological knowledge; biodiversity conservation; rural sustainability

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1. Introduction

Forests, as complex ecosystems, hold significant cultural and ecological values that are intrinsically intertwined [1,2]. The traditional ecological knowledge of forest dynamics, interspecific interactions, disturbance timing and intensity, sustainable harvest levels, and the provisioning of nontimber forest products gained by people inhabiting landscapes for long periods of time creates intricate connections between human and non-human communities [3–5]. Traditional ecological knowledge also supports and sustains cultural connections to forests and landscapes that can be incorporated into contemporary management objectives [6–10]. The cultural values of forests are frequently deeply rooted in human history and traditions, serving as sources of inspiration, spiritual connection, and livelihood for many communities. Forests can hold cultural and spiritual significance, offering sacred spaces for rituals, fostering a deep connection with nature, and preserving sacred species and sites [11–13]. Sacred forests and culturally important landscapes have a tendency to persist in the face of potentially disruptive change, extending the co-benefits provided to human and ecological communities [14–16]. As such, these enclaves of biodiversity have played a crucial role in conserving natural resources and maintaining ecological balance across sometimes rapid economic, demographic, regulatory, and environmental transformations [7,17].

The ecological value of forests to human communities is of paramount importance, providing essential ecosystem services such as regulating services of climate regulation, storm energy attenuation, water purification, providing services of firewood and byproducts, as well as cultural services [18–20]. Forests planted or promoted in and near human settlements and agricultural areas maintain these benefits, which extend to human health and well-being [21,22]. Agroforestry is an effective land management practice that integrates trees and shrubs into agricultural systems, leveraging the ecological, economic, and social benefits of forest resources while enhancing agricultural productivity [23]. Agroforestry is a key approach to forest management that balances environmental conservation with productive activities while also providing diverse ecosystem services [18]. Agroforestry techniques can be applied to sacred forests and other regionally important culturally modified landscapes, thus aiding in the persistence of forest assemblages and the protection of rare species while also supporting cultural traditions [17,24]. Urban forests further exemplify the ecological and cultural significance of trees, including their ability to purify air, mitigate urban heat islands, provide spiritual comfort, and enhance community cohesion [25,26]. In this way, forests can represent socio-ecological systems that provide inherent environmental value as well as benefits to human communities who manage and rely on the ecosystems [27,28].

Considered holistically, certain forests represent durable socio-ecological systems that draw on traditional ecological knowledge, including agroforestry techniques, in urban, peri-urban, and village settings. These forests combine elements of local culture and frequently invoke sacred values while also producing and maintaining tangible benefits for residents, e.g., fengshui forests in South Korea [29] and the mainland [30]. Japanese homestead windbreak forests are one such exemplar of the multiple human and environmental benefits associated with traditional forest management [31]. Homestead windbreaks, known as yashiki-rin in Japanese, have long been integral to rural landscapes across Japan [32,33] and represent the confluence of traditional ecological knowledge, sacred forests, and agroforestry techniques that have aligned to produce a system with multiple benefits to human and natural communities. These tree clusters, typically planted around homes and farms, provide vital ecological services, such as mitigating the adverse effects of strong winds on homes, crops, and livestock in addition to providing a suite of human uses such as medicine, food, timber, and dye [34,35]. The tradition of windbreak planting is rooted in a deep understanding of local environmental conditions, including extreme weather events, that evolved over centuries as an essential practice for protecting rural livelihoods [35–37]. However, the role of these windbreaks in Japanese villages extends beyond mere utility, representing a fusion of cultural heritage and ecological stewardship [38].

One particularly significant example of this tradition is the Fukugi ("Happiness tree", *Garcinia subelliptica*) windbreak system found in Okinawa, Japan's southernmost prefecture [39]. Fukugi trees are central to the cultural and environmental landscape of Okinawa, encircling homes and providing protection from the island's frequent typhoons. These windbreak forests are not only functional but also deeply intertwined with local traditions and practices. For instance, the trees' placement around homes reflects their role in protecting the household, symbolizing a protective barrier against both natural disasters and negative spirits. The dense, lush growth of Fukugi trees is often incorporated into architectural designs, with some traditional Okinawan houses and shrines featuring Fukugi wood or utilizing its shade for leisure spaces. Beyond their architectural significance, Fukugi trees are also embedded in land management systems. The forests help maintain soil health and water retention, benefiting local agricultural practices such as the cultivation of crops like sweet potatoes and sugarcane. In addition to these practical roles, Fukugi trees play a central role in cultural events and rituals. For example, during certain festivals, leaves of Fukugi trees are used. This blend of environmental protection, cultural value, and sustainable land use illustrates the multi-dimensional role of Fukugi windbreak forests in Okinawa [40,41].

However, while much attention has been paid to windbreak practices across Japan, particularly on the mainland, less is known about the unique ecological and historical significance of Okinawa's Fukugi windbreaks, especially in the context of their contribution to sustainable rural landscapes and the cultural connections they embody and support.

Despite their significance, traditional windbreak forests in Japan have been steadily declining due to urbanization, lifestyle changes, and rural depopulation, particularly since the Second World War [41,42]. These shifts have reduced the prevalence of homestead windbreaks, which were once crucial for creating protective microclimates and supporting biodiversity while also supporting rural livelihoods. Given the current global emphasis on climate resilience and sustainable rural development, including agroforestry, reassessing the value of these traditional windbreak forests is crucial.

This study seeks to fill the gap in the literature regarding the ecological and cultural significance of Fukugi windbreak forests in Okinawa. By exploring the arrangement, species composition, and spatial distribution of Fukugi windbreaks, we aim to provide insights into the historical evolution of this practice and its relevance in the context of contemporary landscape management by situating the Fukugi windbreaks within the broader framework of agroforestry systems and ecosystem services. Agroforestry practices like these have long been recognized for their multifunctional roles in enhancing ecological resilience, promoting biodiversity, and supporting sustainable livelihoods. By comparing the Fukugi system to other homestead windbreak practices in Japan and globally, this research contributes to the growing discourse on how traditional forestry practices can offer solutions to modern challenges, such as climate adaptation and rural sustainability. To achieve this, we pose the following research questions:

1. What are the defining ecological and cultural characteristics of homestead windbreak forest landscapes in Okinawa, and how do these features compare to similar agroforestry systems across Japan and globally?
2. What historical and environmental factors influenced the origin and development of the Fukugi tree windbreak system in Okinawa, particularly from its inception during the Ryukyu Kingdom era to its current state, and how has this system supported sustainable rural landscapes over time?

Through these research questions, our goal is to provide general knowledge about the current state and plantation history of the homestead windbreak culture in Japan and to support rural sustainability through continued agroforestry practices in the subtropics.

2. Survey Area and Methods

2.1. Survey Area

Okinawa Prefecture, Japan's southernmost archipelago, lies between the East China Sea and the Pacific Ocean. Its subtropical climate supports rich ecosystems, including coral reefs and Fukugi (*Garcinia subelliptica*) windbreak forests that protect against typhoons. Once the independent Ryukyu Kingdom, Okinawa's culture blends Japanese, Chinese, and Southeast Asian influences. Its strategic location played a key role during World War II. Known for its biodiversity, including endemic species like the Okinawa rail (*Gallirallus* *okinawae*) and Okinawa woodpecker (*Dendrocopos noguchii*) [43], the region's culture reflects deep ties to the ocean and agriculture. Geographically, Okinawa features diverse landscapes, from rugged coastlines to dense and productive forests.

The Yaeyama region (Figure 1), the southernmost part of Okinawa, is renowned for its subtropical climate, diverse ecosystems, and unique cultural heritage [44]. The Yaeyama Islands are known as a region frequently struck by typhoons and suffer significant damage every year [45]. The area includes islands like Ishigaki and Iriomote, known for lush forests, coral reefs, and endangered species such as the Iriomote wildcat (*Prionailurus bengalensis iriomotensis*). The Kuroshio Current supports rich marine life, while the islands' rainforests and coastal environments help regulate the climate and sustain agriculture. The name "Yaeyama" means "eight-layered mountains", symbolizing the region's distinctive terrain and remote island culture. The Yaeyama Islands preserve the Ryukyuan language through local dialects, traditional music featuring the sanshin, and local deities, reflected in rituals at sacred sites and stories celebrating the connection between humans and the environment.

Iriomote Island covers an area of approximately 290 km^2, making it the second-largest island in Okinawa Prefecture [45]. It features mountains ranging from 300 to 470 m, including Mount Komi at 470 m. The Urauchi River (18.8 km long) and Nakama River (7.45 km long) are among the largest rivers in Okinawa, with Urauchi being the longest in the prefecture. The Urauchi River flows northwest from the mountainous region in the southeastern part of Iriomote Island and empties into the East China Sea. Characterized by its reliance on rainwater as its primary source, the river's water levels fluctuate easily, creating a dynamic ecosystem. It supports a dynamic ecosystem, including mangrove forests of *Bruguiera gymnorhiza*, *Rhizophora stylosa*, and *Kandelia obovata*. The river is a symbol of Iriomote's nature and a key tourism resource, with boat rides to "Gunkan-iwa" and hiking trails to the Mariyudu and Kanbira waterfalls. The Nakama flows eastward from the island's southwest into Nakama Port. It is a gentle river flowing through hilly terrain, surrounded by expansive mangrove wetlands that nurture a variety of aquatic life. Despite its relatively modest water volume, the Nakama River plays an essential role as a tourism and ecotourism resource, showcasing the rich biodiversity and subtropical environment of Iriomote Island.

About 90% of the island is covered in subtropical natural forests, with approximately 80% designated as national forest. The island's land use is primarily focused on conservation, with small-scale agriculture and settlements covering 7% of the area. It is largely protected as part of the Iriomote-Ishigaki National Park, promoting ecotourism and environmental preservation. The island is home to natural monuments and rare species, such as the Iriomote wild cat, the yellow-margined box turtle (*Cistoclemmys flavomarginata evelynae*), and the Sakishima looking-glass tree (*Heritiera littoralis*). The primary industries of the island are agriculture, livestock farming, and tourism, with agriculture focusing on sugar cane, rice, vegetables, pineapples, and tropical fruit production. The island's rugged terrain and ecological focus limit large-scale cattle farming, making agriculture and animal husbandry relatively modest compared to other parts of Okinawa. It is surrounded by several small low-relief islands, whose residents historically traveled to Iriomote Island by boat to cut down Fukugi trees from the mountains to build houses. Iriomote National Park was created in 1972, in part as a response to the resource shortage on outlying islands and to prevent timber cutting on Iriomote.

Sonai and Hoshitate (Figure 2) in the northwest and Komi in the east are considered the earliest developed villages on Iriomote Island. Sonai Village contains the oldest wooden thatched house in Okinawa Prefecture (the former Shinmori residence, a designated cultural property). Sonai contains extensive Fukugi homestead windbreaks, characterized by coral stone walls. Komi, located in the eastern part of the island, is said to have been opened around the 14th century. The village has faced cycles of abandonment and migration due to malaria, famine, and the Great Tsunami of Meiwa in 1771. The current Komi village was formed in the latter half of the 18th century. According to statistical data from Taketomi Town, the population of Iriomote Island is 2382 people in 1374 households, with Sonai having 115 people in 62 households (as of March 2023), and Hoshitate containing approximately 99 people in 55 households [46].

The survey sites for the traditional homestead windbreaks on Iriomote Island include Sonai Village and Hoshitate Village. Unlike in the old villages in the middle and northern extent of the Ryukyu Islands, the windbreak landscape in this area does not solely comprise Fukugi trees but also includes a variety of tree species. In Hoshitate village, large trees such as banyan (*Ficus microcarpa*) and others, such as tamanu (*Calophyllum inophyllum*), chinaberry (*Melia azedarach*), also coexist with Fukugi. According to the residents in Hoshitate, many Fukugi trees were originally present, but after World War II, they were sold to people from outside the island for construction timber.

Figure 1. Location of Iriomote Island (Iriomotejima) within the Yaeyama Region of the Ryukyu Archipelago of southern Japan. Data source: The figure was created using the maps from the home page of the Geospatial Information Authority of Japan [47].

Figure 2. Location of the two survey villages, Sonai (**left**) and Hoshitate (**right**) on Iriomote Island, Japan (aerial imagery and location map adapted from Google Earth Pro).

2.2. Survey Methods of Village Homestead Windbreak Forests

Surveys of Fukugi trees in Sonai Village were conducted in December 2020 and March 2021 (Figure 2). The same methods used in previous surveys conducted in the Yaeyama region were employed (see [48]). In Sonai Village, we measured the diameter at breast height (DBH, 1.3 m above ground) of all Fukugi trees with a diameter of 5 cm or greater. We measured the height of each Fukugi tree and the orientation directions of Fukugi trees relative to the houses in the center of the homestead.

On high ground to the west of Sonai, there are remnants of an old village site known as Kamimura that is currently utilized as cultivated land. In Kamimura, subtropical plants thrive, and Fukugi homestead forests can also be found. The largest Fukugi trees currently seen in the contemporary village are similar in size to those in Kamimura. Kamimura is connected to the local residential area called Shimomura by a historic road called Pisada Road. The current village expands west of Prefectural Road 215, making the homesteads located there part of the survey area.

In Hoshitate Village, field surveys on tree composition were conducted three times: in March 2021, and in August and December 2023. Each survey lasted approximately one week but was frequently interrupted by typhoons or heavy rain. We measured the height and DHB of all trees greater than 5 cm, and we recorded the species and direction to the closest house.

In addition to measuring trees during the field survey, we conducted interviews with village residents to help contextualize the results from our forest measurements. A snowball sampling approach was applied to reach the appropriate informants. Interview questions were adapted from an earlier study of village homestead forests across a development gradient in Okinawa Prefecture [49] and asked when and why specific tree species were planted and how villagers used specific types of trees in the past. The interviews incorporate essential local knowledge of historical and contemporary agroforestry practices and shed light on the human influences on forest composition, density, location, and relationship to the village settlement.

2.3. Survey Methods of Naturally Regenerating Fukugi Trees Outside Villages

On 29 March 2021, we conducted a mountain survey with a local guide (Mr. Chouken Ishigaki, a former technical staff member at the Tropical Biosphere Research Center, University of the Ryukyus). As seen in Figure 3, large Fukugi trees have different crown shapes compared to Itajii (*Castanopsis sieboldii*) and Ryukyu pine trees (*Pinus luchuensis*). Being taller than other tree species, the pointed tops of the Fukugi trees can be easily spotted from a distance. Thus, we were able to locate Fukugi groups using binoculars. There were no mountain paths, so we ascended upstream along the Urauchi River.

We measured and recorded the diameters (DBH, 1.3 m above ground) of Fukugi trunks with diameters of 5 cm or greater. Tree heights were not measured as in homestead forests because the dense forest canopy made accurate measurements difficult. Locations of Fukugi trees were recorded using a Garmin GPS 64. The GPS data were later imported into Google Earth for visualization.

2.4. Data Analysis

Fukugi tree ages were estimated from measured DBH values using a simple equation derived by Hirata [50]:

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

where y is the estimated tree age, and x is the DBH (cm) at 1.3 m above ground level. Due to the inherent uncertainty in the age calculation, our analyses used 50-year age class bins.

Figure 3. The pointed tops of Fukugi trees (circled) rising above the surrounding forest canopy.

Total basal area is a common way to normalize the density of trees across species in a stand, and it shows dominance by integrating tree size and frequency of abundance. The total basal area is calculated as below [51]:

$$BA_{total} = \sum \frac{\pi \times \left(\frac{DBH(cm)}{2}\right)2}{10,000} \quad (2)$$

where BA is the basal area of a tree, and DBH is the diameter of the trunk measured 1.3 m above the ground. Each tree within a species is summed, and the total basal area by species is reported below.

Statistical analyses were performed using SPSS software (v.24).

3. Results

3.1. Homestead Windbreak Tree Species Composition in Sonai Village

An overview of the remaining fragmented Fukugi tree lines in Sonai Village is presented in Table 1. A total of 693 Fukugi trees were recorded. Among them, DBH data for 14 trees were not recorded. As the trunks were sometimes tightly wrapped by vines such as the banyan tree (*Ficus microcarpa*) and Pothos (*Epipremnum pinnatum*) at a height of 1.3 m, vines that could be removed were temporarily detached for measurement, while trees with vines that could not be removed were left unmeasured. Height measurements for seven trees could not be collected.

The average DBH, height, and estimated age of the Fukugi trees were 21.2 cm, 6.2 m, and 82.8 years, respectively. The maximum values for DBH, height, and estimated age were 68 cm, 18.5 m, and 272 years. About 25% of the Fukugi trees in Sonai Village had a DBH of 12 cm or less, indicating strong ongoing recruitment. Conversely, approximately 10% had a DBH of 49 cm or more, signifying the presence of large Fukugi trees as well. Figure 4 displays a scatter plot of tree height and the estimated age of the Fukugi trees, showing that most Fukugi are under 150 years old and under 12 m tall. While the average height of Fukugi is 6.2 m, about 25% exceed 7.8 m, and approximately 10% exceed 9.61 m.

Figure 5 shows the positions of Fukugi trees relative to the houses. Most Fukugi trees are located on the east side of the homestead, followed by the north side. Trees on the east and north sides account for about 62% of the total. The fewest Fukugi are on the west side. This trend is consistent with other regions in the prefecture. The southern part of Sonai village faces the sea, resulting in a distribution of Fukugi trees on the south side similar to that of the north side.

Table 1. Overview of Fukugi in Sonai Village, Iriomote Island.

	Tree Height (m)	DBH (cm)	Estimated Age (Years)
Tree number	686	679	669
Average	6.20	20.7	82.8
Std. Dev.	2.50	14.0	55.9
Max	18.52	68	272
Min	0.33	5	20
5th Percentile	2.51	7.4	6
25th Percentile	4.34	12	10.1
50th Percentile	5.95	19.5	16.4
75th Percentile	7.78	31.7	27.5
90th Percentile	9.61	49	41.2

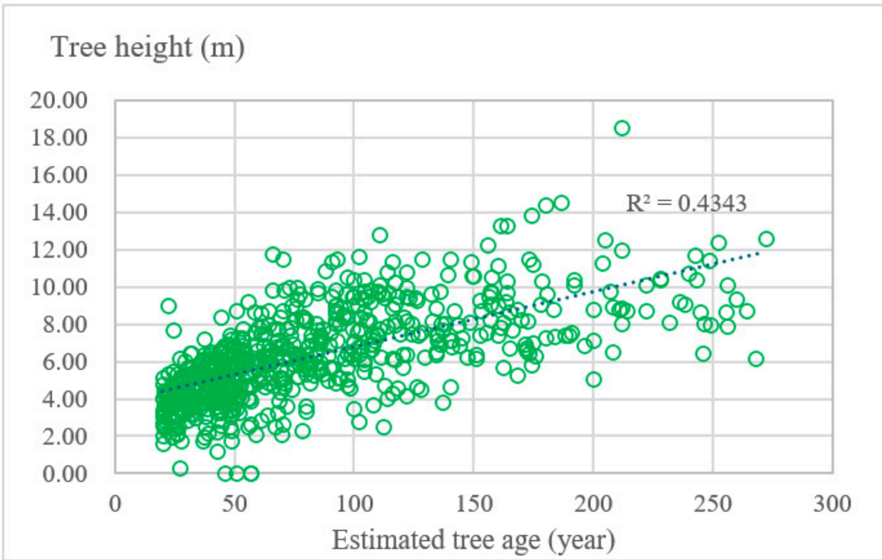

Figure 4. Scatter plot of estimated tree age and height.

Figure 6 depicts homesteads that have Fukugi trees over 250 and 200 years old. Large Fukugi trees are often found facing the sea on the north and south sides of the village. Particularly on the south side, there are several homesteads surrounded by large Fukugi trees. However, the central part of the village has very few Fukugi trees. Sonai village is experiencing depopulation, and many of the homestead forests are abandoned and not maintained.

Figure 7 illustrates the Fukugi forest belt. From Figure 7, it can be seen that Fukugi forest belts remain on the south and north sides of the village, with a definite distribution on the east side.

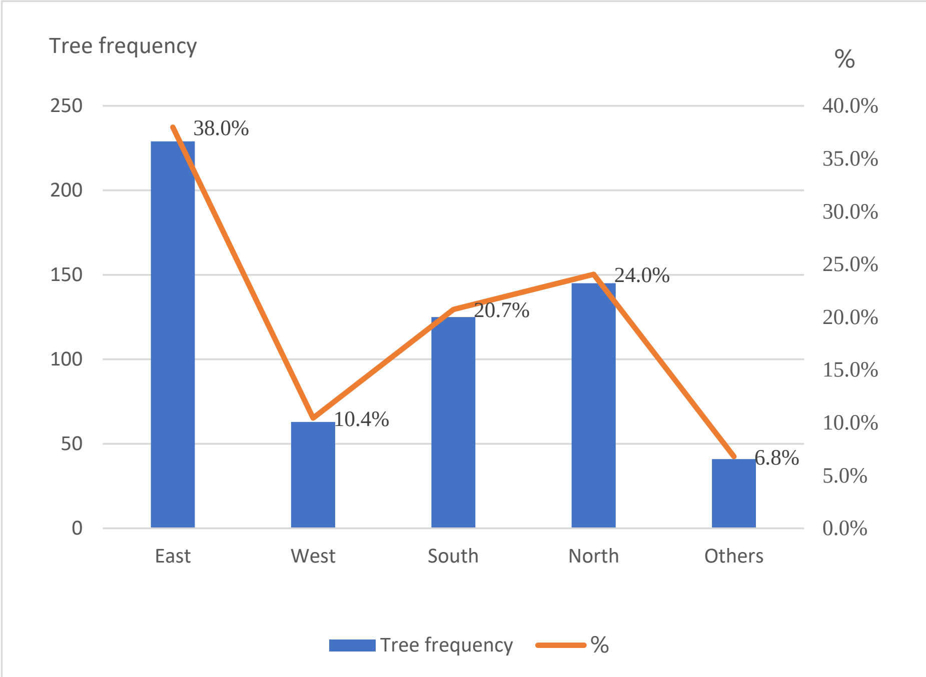

Figure 5. Fukugi tree characteristics in Sonai Village. Size–age relationship for Fukugi trees. The orientation of Fukugi trees as seen from the center of the house "Others" refers to trees that are oriented towards the corners of the residences rather than the more frequently observed cardinal directions.

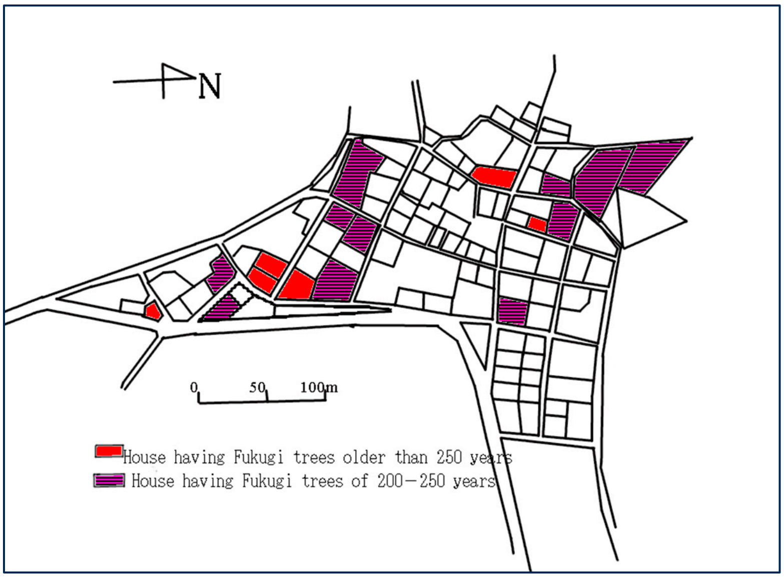

Figure 6. Homesteads in Sonai Village with Fukugi trees over 250 and 200 years old.

3.2. Homestead Windbreak Tree Species Composition in Hoshitate Village

A total number of 1102 individual trees were measured and recorded in Hoshitate (Table 2). The species composition of the homestead windbreak shows a diverse array of tree species, with Fukugi (*G. subelliptica*) being the most prevalent, accounting for 340 individuals, an average DBH of 24.9 cm, and a total basal area of 16.491 m^3. This species is followed by *Calophyllum inophyllum*, with 224 individuals, a larger average DBH of 37.8 cm, and the highest total basal area of 25.134 m^3. These two species dominate the composition of the windbreak, making up a significant portion of the biomass and structural density.

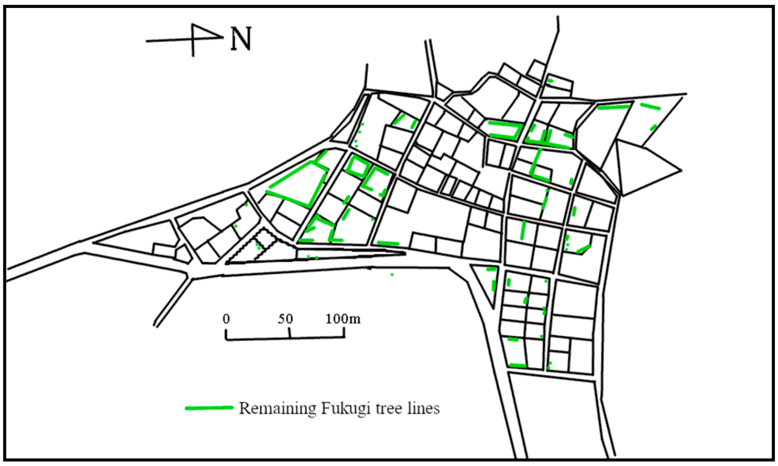

Figure 7. Remaining Fukugi homestead forest belts in Sonai Village.

Table 2. The 40 tree species recorded in the homestead windbreaks in Hoshitate.

Species	No	Average DBH (cm)	Total Basal Area (m^3)
Garcinia subelliptica	340	24.9	16.491
Calophyllum inophyllum	224	37.8	25.134
Diospyros ferrea	102	13.1	1.376
Planchonella obovata	81	19.1	2.320
Podocarpus macrophyllus	40	15.2	0.721
Murraya paniculata	38	10.5	0.329
Morus australis	32	29.2	2.137
Bischofia javanica	16	33.8	1.436
Melia azedarach	15	54.5	3.491
Ficus microcarpa	13	33.2	1.123
Macaranga tanarius	11	18.0	0.279
Melanolepis multiglandulosa	10	14.2	0.158
Premna serratifolia	10	8.6	0.058
Ficus septica	8	12.2	0.093
Cinnamomum camphora	7	36.7	0.739
Terminalia catappa	7	20.6	0.234
Nageia nagi	7	12.7	0.089
Citrus depressa	7	8.1	0.036
Cinnamomum pedunculatum	6	9.2	0.040
Mangifera indica	5	16.1	0.102
Diospyros maritima	4	8.4	0.022
Codiaeum variegatum	4	8.2	0.021
Ficus superba	3	55.5	0.725
Psidium guajava	3	9.2	0.020
Celtis boninensis Koidz	2	9.4	0.014

Table 2. *Cont.*

Species	No	Average DBH (cm)	Total Basal Area (m^3)
Pittosporum tobira	2	9.3	0.014
Euonymus japonicus	2	5.5	0.005
Erythrina variegata	1	114.0	1.020
Casuarina equisetifolia	1	78.0	0.478
Litchi chinensis	1	28.0	0.062
Machilus thunbergii	1	23.0	0.042
Arecaceae	1	22.5	0.040
Bauhinia variegata	1	15.5	0.019
Trema orientale	1	13.2	0.014
Euonymus tanakae Maxim	1	12.5	0.012
Callicarpa japonica	1	11.8	0.011
Distylium racemosum	1	11.5	0.010
Eriobotrya japonica	1	9.4	0.007
Pouteria campechiana	1	9.0	0.006
Gardenia jasminoides	1	7.0	0.004

Other species, such as *Diospyros ferrea* (102 individuals, 13.1 cm average DBH) and *Planchonella obovata* (81 individuals, 19.1 cm average DBH), are also notable, though their total basal areas (1.376 m^3 and 2.320 m^3, respectively) are much smaller in comparison. *Podocarpus macrophyllus*, while only represented by 40 individuals, shows an average DBH of 15.2 cm and contributes 0.721 m^3 to the total basal area. Similarly, *Murraya paniculata* (38 individuals) has a smaller average DBH of 10.5 cm and a basal area of 0.329 m^3.

Several larger species, such as *Melia azedarach* and *Ficus superba*, stand out due to their large DBH measurements of 54.5 cm and 55.5 cm, respectively, though they are represented by fewer individuals (15 and 3). *Melia azedarach* contributes a substantial 3.491 m^3 to the total basal area, despite its smaller population, indicating its role as a large canopy tree within the windbreak.

Smaller trees like *Premna serratifolia* and *Citrus depressa* show lower DBH values (8.6 cm and 8.1 cm, respectively) and relatively small contributions to the total basal area. Additionally, rare species such as *Erythrina variegata*, with only one individual but a notably large DBH of 114 cm, contribute significantly to the structure with a basal area of 1.020 m^3.

Overall, the windbreak is composed of a mix of dominant, medium, and rare species, each contributing differently to the structural and ecological functions of the homestead. The presence of large trees alongside smaller ones highlights the diverse structure of windbreaks, which likely serves both protective and environmental roles in the landscape.

The box plot figure (Figure 8) summarizes the diameter at breast height (DBH) measurements of various tree species, including *G. subelliptica*, *C. inophyllum*, *D. ferrea*, *P. obovata*, *B.javanica*, *P. macrophyllus*, *and M. azedarach*. The DBH values for these species range from 0 to 100 cm, highlighting the variation in tree sizes within the surveyed area. The data provide insights into the forest composition, where species such as *P. macrophyllus* and *B. javanica* demonstrate a broad range of diameters, suggesting a mixture of both young and mature trees. This variation is crucial for understanding the structural diversity and ecological dynamics of the forest as well as the role of villagers in maintaining and promoting forest structure and composition.

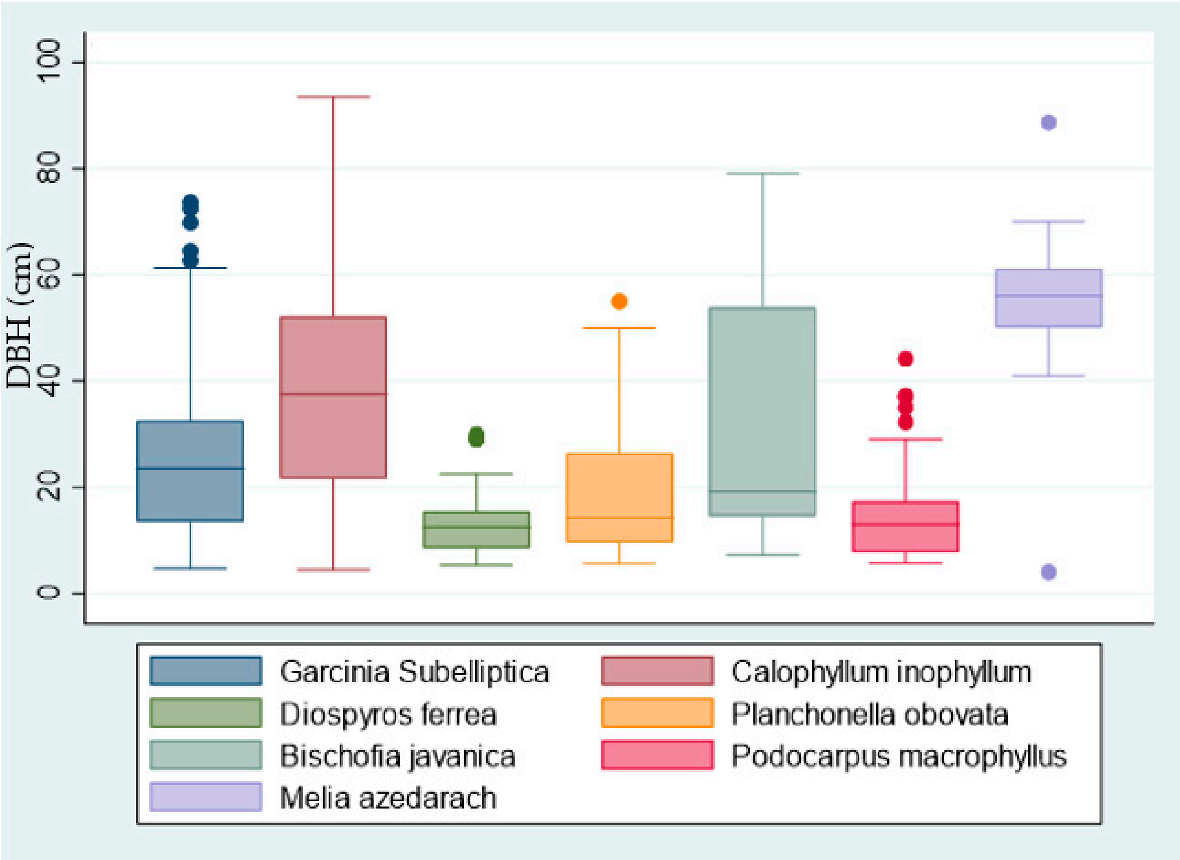

Figure 8. Box plot of the major tree species surveyed in Hoshitate Village.

The informant told us that *C. inopyllum* was historically planted to make furniture when the girls grew up and married. *P. macrophyllus* is frequently used as the pillar of traditional timber houses. *D. ferrea* was used to construct the traditional Okinawan musical instrument, sanshin.

Figure 9 illustrates the spatial distribution of Hoshitate homesteads with large Fukugi trees. Large Fukugi trees are often found facing the sea on the north and west sides of the village, which mirrors the pattern observed in Sonai and likely reflects the orientation of Hoshitate to the ocean. Homesteads in Hoshitate are more generally surrounded by large Fukugi trees than in Sonai. Unlike in Sonai Village, the central part of Hoshitate retains a number of large Fukugi trees. Figure 10 shows the frequency of Fukugi trees by their cardinal direction orientation to the nearest homesteads.

3.3. Fukugi Groups in the Mountains of Iriomote Island

Two naturally regenerating stands of Fukugi were found in the northern part of Iriomote Island. As shown in Figures 11–13, the two Fukugi stands are found at the foot of the mountains on the western side of Urauchi River and at the mouth of the Yonada River. The Fukugi groups along the Urauchi River are located below an elevation of 50 m, while those at the mouth of the Yonada River grow on slopes below 100 m. A common characteristic of the habitats of the two Fukugi groves is that they are situated on low mountains near river mouths.

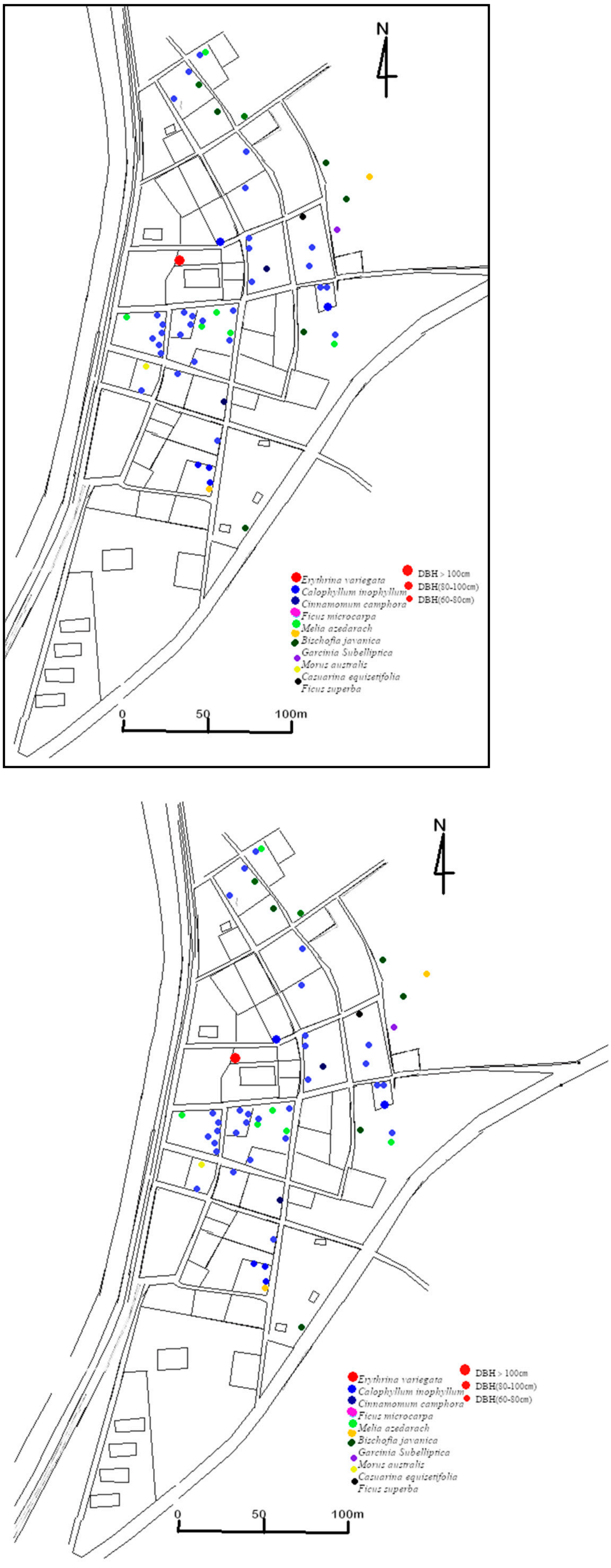

Figure 9. *Cont.*

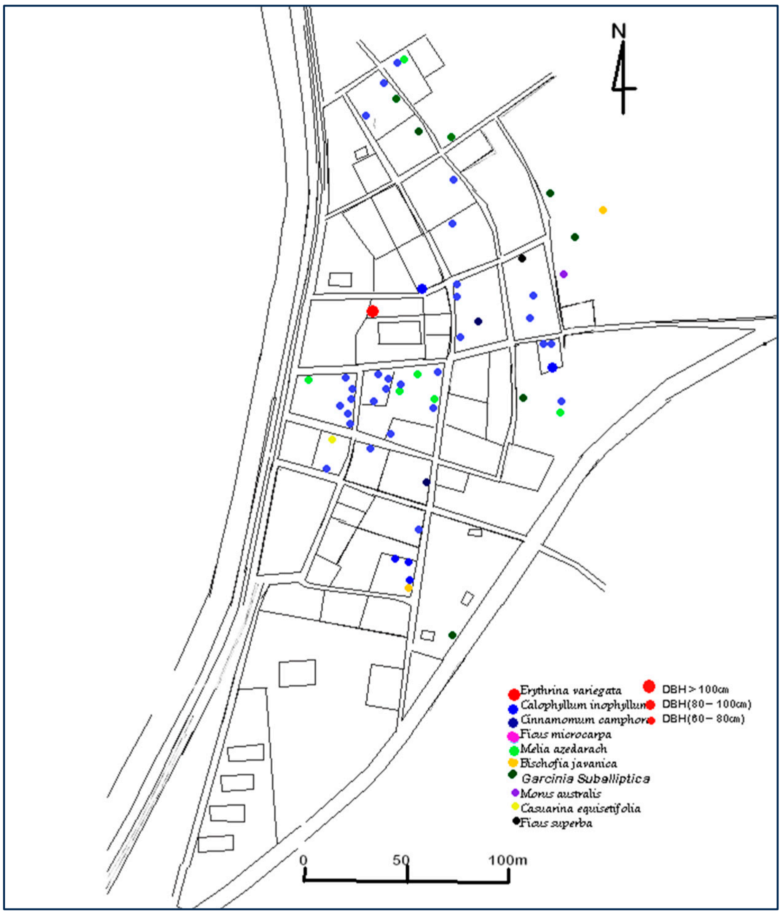

Figure 9. Distribution of large trees in Hoshitate Village.

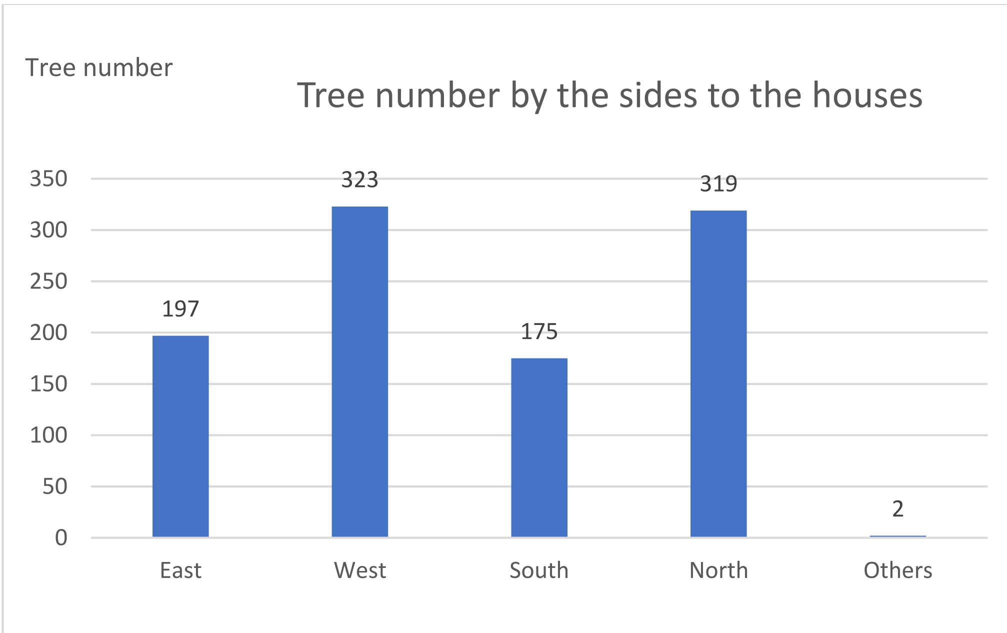

Figure 10. The orientation of Fukugi trees in Hoshitate village as seen from the center of the house. "Others" refers to the corners of the residences and lies between the cardinal directions.

Figure 11. Fukugi groves on the hills behind Sonai Village and in the mountains upstream of the Urauchi River.

Figure 12. Naturally growing Fukugi grove in the upper reaches of the Urauchi River (Google Earth satellite version and topographic relief map version). The red circle in the left picture presents the Fukugi grove.

Figure 13. Naturally growing Fukugi grove on Mt. Sonaidake, east of Sonai Village (Google Earth version and topographic map version). The red circle in the left picture presents the Fukugi grove.

Table 3 shows the diameters at breast height of the two natural Fukugi groups. In the upstream area of Urauchi River, 21 Fukugi trees were measured, while 45 were measured on Sonai Mountain. The maximum and average DBH at a height of 1.3 m above ground for Fukugi in the upstream area of the Urauchi River were 48 cm and 12.8 cm, respectively, while for Sonai Mountain, they were 35 cm and 10.3 cm. The larger average size of Fukugi in the upstream area of the Urauchi River may be due to its inaccessibility, preventing the harvesting of larger specimens. The largest Fukugi tree (Figure 14), estimated to be about 200 years old, has a large cavity in its trunk, which may explain why it remains unharvested.

Table 3. Naturally regenerated Fukugi forests on Iriomote Island.

Location	Number	Max (cm)	Mean (cm)	Standard Deviation (cm)
Urauchi River upstream	21	48	12.8	10.7
Hoshitate Village back mountain	45	35	10.3	8.1

Figure 14. The largest Fukugi (*Garcinia subelliptica*) tree in the natural forest located upstream of the Urauchi River (DBH: 48 cm; Estimated age: 192 years).

The appearance of the Fukugi natural forest is shown in Figure 15. The trunks grow straight up, and their height exceeds that of surrounding trees like Itajii. They have very slender branches. It seems that Fukugi is considered a valuable timber species on Iriomote Island. According to resident testimonies, people from surrounding islands have sourced timber from Iriomote Island. Consequently, the mountains contain very few healthy and large Fukugi trees compared to village homestead forests.

Figure 15. The natural Fukugi forest on Sonai Mountain.

4. Discussion

4.1. Traditional Island Village Homestead Windbreaks in Okinawa

The Fukugi tree windbreak forests in the villages of Sonai and Hoshitate on Iriomote Island represent a distinct element of Okinawan rural landscapes. Unlike homestead windbreaks on Japan's mainland, which commonly feature species such as pines and cedars, the Fukugi windbreak forest landscape in Okinawa is characterized by close integration of homes and vegetation, with trees encircling houses on all four sides. This arrangement not only mediates local microclimates and protects against the island's frequent typhoons but also contributes to biodiversity conservation and the preservation of cultural heritage via traditional agroforestry practices [52,53]. In this way, Okinawan Fukugi windbreak forests can also be said to produce not only ecosystem services but also cultural ecosystem services [54].

While similar homestead windbreak systems are found in other parts of Japan, such as the Igune in northeastern Japan and the Tsukijimatsu in Shimane Prefecture, Okinawa's Fukugi windbreaks differ in both species composition and spatial arrangement [55]. As in other locations in Japan, Fukugi windbreak forests are oriented to reduce windspeeds from all directions, with a bias towards the more vulnerable direction experienced during typhoons or other coastal storms [36]. These differences underscore the adaptability of traditional agroforestry practices to local environmental and cultural contexts. The persistence of these windbreaks highlights their ecological value, particularly in providing wind protection, enhancing microclimates, and supporting rural livelihoods through the provisioning of timber and non-timber forest products. Fukugi are used as lumber and their fruit is eaten, and the trees are used in traditional medicine to treat malaria and other fevers, inflammation, and various skin disorders, and the bark can be used to make a textile dye while the sap contains latex [56,57].

This study confirms that Fukugi windbreaks are an essential feature of Okinawan villages, contributing significantly to ecosystem services that expand beyond ethnobotanical uses and non-timber forest products, such as disaster mitigation, carbon sequestration, and biodiversity support [58]. These findings align with global literature on traditional agroforestry systems, which have been recognized for their multifunctional roles in rural resilience, ecological stability, and cultural continuity [59]. The Fukugi windbreak system provides a model of sustainable landscape management tuned to tropical and subtropical landscapes that can inform conservation efforts in other regions facing similar environmental and social challenges.

4.2. Evolution of the Fukugi Windbreak System

The historical development of Fukugi windbreaks in Okinawa reflects a strategic response to the island's climatic conditions and limited land resources. It is believed that seeds of Fukugi from the coastal areas of Indonesia and the Philippines reached the coast of Iriomote Island and washed up on the low mountains at river mouths, marking the beginning of the adoption of Fukugi avenues in the Ryukyu Islands. The transition from diverse, multi-species windbreak forests in more northerly locations to those dominated by Fukugi trees represents a shift in local adaptation strategies, driven by both demographic changes and the evolving needs of rural communities. The simplification of species composition, while potentially reducing biodiversity, allowed for the efficient management of limited space and resources while provisioning a useful set of timber and non-timber forest uses.

The evolution of Fukugi windbreaks parallels the broader trends in cultural landscapes globally, where traditional knowledge and practices have shaped sustainable land-use systems over time. Similar agroforestry practices in Southeast Asia, Europe, and the Americas have demonstrated the importance of integrating ecological and cultural factors in landscape management [60,61]. The case of Okinawa's Fukugi windbreaks adds to this body of knowledge, offering insights into how rural communities can maintain resilience in the face of environmental pressures.

This study suggests that the practice of planting Fukugi trees likely originated in the Yaeyama region and spread throughout Okinawa. This process mirrors the dispersal of other traditional agroforestry systems, where local adaptations to environmental constraints have led to the development of regionally specific land-use practices. By documenting the ecological and cultural significance of Fukugi windbreak forests, this study contributes to a deeper understanding of the interplay between natural resource management and cultural heritage preservation in rural landscapes.

4.3. Contribution to Ecosystem Services and Cultural Heritage

This study demonstrates the multifunctional contributions of Fukugi windbreak forests, which provide a wide range of ecological and cultural benefits to Okinawan communities. From our field surveys in the Sonai and Hoshitate villages, we observed that these forests play a crucial role in protection against typhoons, supporting local biodiversity, and creating microclimates that enhance agricultural productivity. In Hoshitate, the presence of diverse tree species alongside Fukugi highlights the structural complexity of these forests, which contributes to ecological resilience within rural landscapes.

In addition to their ecological benefits, our findings underscore the cultural significance of Fukugi trees. These windbreaks serve as symbols of resilience and continuity within Okinawan communities, rooted in their heritage from the Ryukyu Kingdom era. The integration of Fukugi trees with coral walls, traditional architecture, and small-scale agricultural production forms a unique cultural landscape that reflects a historical adaptation to environmental challenges [62]. These elements collectively define the Ryukyu Archipelago's distinctive identity and underscore the importance of preserving these windbreak systems.

The study also highlights the growing recognition of Fukugi windbreaks as valuable resources for sustainable tourism in Okinawa. Local residents described the windbreaks primarily in functional terms, such as "windbreak" and "firebreak", while tourists emphasized their esthetic and spiritual qualities, using terms like "greenery", "nature", and "healing" [63]. These contrasting perspectives underscore the dual role of Fukugi windbreaks as both functional and cultural assets. This aligns with broader trends in nature-based tourism across Japan, where forests are increasingly valued for their recreational and therapeutic benefits [54,64].

Globally, traditional agroforestry systems, including Fukugi windbreaks, are recognized for their contributions to climate adaptation and rural sustainability. Fukugi forests exemplify how cultural practices can be integrated into conservation strategies to address contemporary challenges, such as climate change and rural depopulation [65,66]. However, our findings also emphasize the need for ongoing maintenance and local engagement to ensure the long-term sustainability of these landscapes [67,68].

As rural landscapes worldwide face pressures from environmental and demographic changes, the Fukugi system provides valuable insights into the adaptive potential of traditional land-use practices. By integrating cultural heritage with ecological resilience, these windbreaks offer lessons for balancing conservation and sustainability in similar regions [69].

5. Conclusions

This study sheds light on the ecological and cultural importance of Fukugi windbreaks in Okinawa, particularly in the villages of Sonai and Hoshitate on Iriomote Island. The data from these villages confirm the central role of Fukugi trees in shaping the rural landscape, offering both wind protection and contributing to the region's biodiversity and sustaining its unique cultural heritage. The study highlights the distinct characteristics of Okinawan windbreaks, which differ from those found on mainland Japan in terms of species composition and spatial arrangement, and which provide a concrete link to the region's history and traditional livelihoods.

The findings suggest that Fukugi windbreaks, with their multifunctional roles, continue to be crucial to the sustainability of rural landscapes in Okinawa. By protecting homes and crops from the island's harsh climatic conditions and frequent storms while supporting local biodiversity, Fukugi trees provide vital ecosystem services that contribute to the resilience of these communities. Additionally, their cultural significance, both as symbols of resilience and continuity, as well as their material utility as wood and for non-timber products, enhances their value, making them a unique example of how traditional forest management practices can contribute to modern sustainability efforts, even amid demographic and economic transformations.

However, the continued diminishment of rural populations and the declining maintenance of Fukugi forests present challenges to their preservation. Engaging local communities in the conservation of these windbreaks and promoting sustainable management practices are essential to ensuring their future survival. This study underscores the need for policies that recognize the broader ecological and cultural value of Fukugi windbreaks, not only in Okinawa but also in other regions where traditional land-use practices are at risk of being lost.

In conclusion, the Fukugi windbreak system in Okinawa offers a model of sustainable rural landscape management that integrates cultural heritage with ecological resilience. By fostering conservation efforts and promoting the multifunctional roles of these windbreaks, policymakers, and local communities can ensure that Fukugi trees continue to provide valuable ecosystem services and cultural benefits for generations to come.

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