












ARTICLE

Research Restoring the Lost Primary Forest Ecosystem in Can Gio to Become the First Biosphere Reserve in Vietnam

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ABSTRACT

Research on the process of restoring the lost primary forest ecosystem in Can Gio to become the first biosphere reserve in Vietnam. This is a pristine mangrove forest ecosystem from the 1960s, which was destroyed by humans and transformed into shrubland and regenerated trees in the 1970s. This forest ecosystem affects the environment and ecology of over 14 million residents of Ho Chi Minh City. A bold plan in 1997 to restore the Can Gio primary forest, transforming it into a secondary forest with high biodiversity and restoring natural plant communities, resulted in the full restoration of plant components and led to its recognition as Vietnam's first biosphere reserve in 2000. The growth process of *Rhizophora apiculata* contributed significantly to the successful restoration of this forest. Statistical research on plant communities and growth processes of mangrove trees, the dominant species accounting for over 90% of the plant species in the Can Gio mangrove forest, is a particularly successful experience in Vietnam. The contribution of the growth process of *Rhizophora apiculata* from 1977 to 2000 played a significant role in the successful restoration of the Can Gio primary forest. This study investigated the growth process of tree trunk diameter (D1.3 m), height (Ht), trunk

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volume (Vt) (m^3 /tree, density (N/ha), and forest volume (M) (m^3 /ha). These results assessed the contribution of forest growth to the restoration of the Can Gio primary forest, transforming it into the first biosphere reserve in Vietnam.

Keywords: Primary Forest Ecosystem; *Rhizophora apiculata*; Secondary Forest Ecosystem; Can Gio-Ho Chi Minh City; Vietnam

1. Introduction

In 1977, the Can Gio mangrove forest ecosystem was destroyed, with more than 90% of the area no longer having forest cover. *Rhizophora apiculata* Blume trees were planted to restore the forest from 1977 to 1997. The forest has recovered, with trees of all ages from 25 to 45 years. The United Nations Educational, Scientific and Cultural Organization (UNESCO) recognized the *Can Gio Mangrove Biosphere Reserve* as the first biosphere reserve in Vietnam on January 21, 2000^[1]. According to a survey in 2022, *Rhizophora apiculata* plantations cover the entire Can Gio mangrove forest, with an area of more than 17,000 ha of forest, restoring the primary forest ecosystem to become a secondary forest ecosystem, with the full components of the previous plant community, contributing many important ecological values and improving the environment to cope with climate change^[2]. There are many research topics on mangrove forest development^[3-5], but research on the ecosystem of plant communities, the development of *Rhizophora apiculata* forests in Can Gio aged from 25 to 45 years, is still limited. Studying the growth of 10-30-year-old planted forests in Can Gio, on three types of low, medium, and high sites^[6], it was found that the growth index was highest in low sites, followed by medium sites, and lowest in high sites. Studying planted mangrove forests in Ben Tre on three types of sites (1) deep mud, (2) medium mud, (3) shallow clay, also found that the growth of individual trees at the site^[7].

Research on the restored plant community, including the study of the growth process of *Rhizophora apiculata*, a species that plays a significant role and accounts for over 90% of the restored secondary forest area “*Research on the process of restoring the lost primary forest ecosystem in Can Gio to become the first biosphere reserve in Vietnam*” has been carried out as part of the research project.

Overall objective: To identify restored primary forest plant communities that have become secondary forests

with a full range of plant components in the primary forest ecosystem, and to study the growth of *Rhizophora apiculata* Blume on two types of forest land terrain, contributing to mangrove forest theory, building a scientific basis for technical solutions, and contributing to sustainable forest management of the forest ecosystem.

Specific objectives: To re-evaluate the restored plant community system, and to study the growth of *Rhizophora apiculata*, including diameter ($D_{1.3av}$), height (H_{tav}), volume (V_{av}), forest density (N), and forest volume (M) according to age at two types of sites.

Scope and subjects of study: Plant communities in mangrove forest ecosystems and the growth process of *Rhizophora apiculata* Blume plantations. The subjects of study are the forest age stages from the planting years 1977, 1982, 1987, 1992, and 1997 on two types of terrain: lowland and highland in the Can Gio protection forest. Data collection locations: Sub-areas 8, 6B, 15A, and 24 in the Can Gio protection forest.

Research indicators: The plant community is synthesized from reports of the Can Gio Protective Forest Management Board, Ho Chi Minh City. The growth process includes several indicators such as diameter ($D_{1.3}$), tree height (Ht), stem volume (Vt), average forest density (N), and average forest volume (M) according to forest age classes corresponding to the planting years 1977, 1982, 1987, 1992, and 1997 on lowland and highland terrains.

2. Materials and Methods

2.1. Evaluate a Reforestation Strategy That Transforms Regenerated Shrubland into a Secondary Forest Modeled after a Primary Forest

To assess the restoration of the original primary mangrove forest in the Can Gio area, the following three steps can be summarized:

Step 1: Receiving a resource from wasteland and re-generating shrubs.

Step 2: Surveying and establishing a plan for the original primary forest.

Step 3: Restoring the forest's current state using native tree species and evaluating it through a comparative secondary ecosystem.

Identify plant communities: Based on biodiversity survey reports from the Can Gio Mangrove Management Board, combined with field surveys conducted during forest growth investigations, plant communities were identified.

2.2. Data Collection Methods for Growth Surveys

Indicators: A (ages), $D_{1.3av}$ (cm), H_{tav} (m), V_{tav} (m^3), N_{av} (tree/ha), M_{av} (m^3/ha)^[8].

Based on forest cover maps and soil maps, divided by age class and terrain, survey transects were established:

The survey transects consist of 30 plots, each with an area of 500 m^2 (25×20 m), age classes V, VI, VII, VIII, IX (each age class is 5 years), comprising 6 plots (3 plots for lowland terrain and 3 plots for highland terrain)^[9,10] (**Table 1 and Figure 1**).

Table 1. Geographic Coordinates of the Survey Plots.

No.	Coordinates UTM 48P		Survey lines	Plot Symbol	Soil Terrain	Age Levels
	X	Y				
1	704,630	1,173,112	1	1O 1	High	V
2	704,630	1,173,137	1	1O 2	High	V
3	704,630	1,173,162	1	1O 3	High	V
4	704,051	1,169,357	2	2O 1	Low	V
5	704,051	1,169,381	2	2O 2	Low	V
6	704,051	1,169,406	2	2O 3	Low	V
7	696,487	1,158,801	6	6O 1	High	VI
8	696,464	1,158,809	6	6O 2	High	VI
9	696,440	1,158,818	6	6O 3	High	VI
10	706,726	1,164,964	5	5O 1	Low	VI
11	706,739	1,164,942	5	5O 2	Low	VI
12	706,751	1,164,920	5	5O 3	Low	VI
13	696,110	1,161,323	8	8O 1	High	VII
14	696,126	1,161,342	8	8O 2	High	VII
15	696,142	1,161,362	8	8O 3	High	VII
16	696,119	1,165,680	7	7O 1	Low	VII
17	696,110	1,165,658	7	7O 2	Low	VII
18	696,101	1,165,636	7	7O 3	Low	VII
19	694,652	1,165,493	11	11O 1	High	VIII
20	694,653	1,165,517	11	11O 2	High	VIII
21	694,653	1,165,543	11	11O 3	High	VIII
22	708,693	1,164,405	4	4O 1	Low	VIII
23	708,675	1,164,387	4	4O 2	Low	VIII
24	708,659	1,164,369	4	4O 3	Low	VIII
25	699,627	1,161,675	13	13O 1	High	IX
26	699,627	1,161,649	13	13O 2	High	IX
27	699,628	1,161,625	13	13O 3	High	IX
28	697,186	1,160,333	14	14O 1	Low	IX
29	697,208	1,160,318	14	14O 2	Low	IX
30	697,229	1,160,302	14	14O 3	Low	IX

**THE STATUS MAP OF THE MANGROVE FOREST IN CAN GIO, HO CHI MINH CITY, VIETNAM
BASED ON NORMALIZED DIFFERENCE VEGETATION INDEX -NDVI**

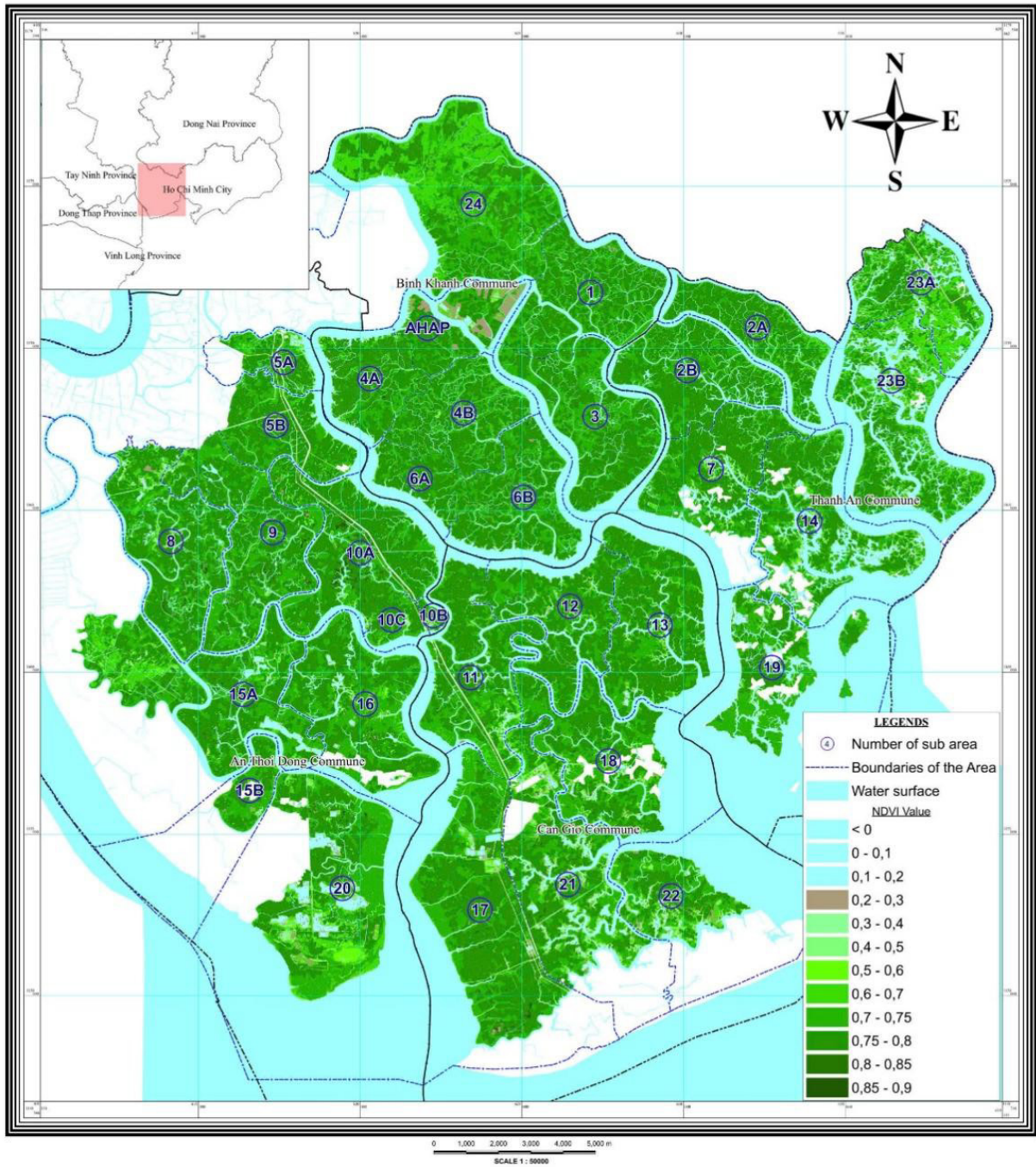


Figure 1. Layout diagram of the study area survey plots.

Measure diameter D1.3 m: Measure circumference C1.3 m, $D1.3 = C1.3/\pi$ ($\pi = 3.1416$). Unit is cm. Measure height Ht: Measure using a Blume Leiss ruler. Tree quality (a, b, c): a: Straight tree, good growth, no pests or diseases, no pruning. b: Crooked trunk, uneven canopy, no pests or diseases, average growth rate. c: Crooked trunk, missing top, blistered, diseased, dry or dead tree. Measure all trees in the survey plot.

2.2.1. Forest Structure Description Method

Based on the age levels, the planting year, age (A), diameter (D1.3 m), height (Ht) and calculate statistical characteristics using Excel software.

Forest structure on age levels and soil terrain N%/D_{1.3} and N%/H_t.

$$N\% = n_i * 100/N \quad (1)$$

n_i: Number of trees in the middle has value i.

N: Total number of trees each age level/ha.

N/ha = n * 10,000/1500 (n is number of trees in 3 plots each age levels/1500 m²).

2.2.2. Study Methods of Individual Growth on Forest Trees

Individual tree, the corelation between (D_{1.3av}, H_{tav}) and tree volume (V_{av}) to age (A).

Forest, the correlation between N, number of trees/ha, volume (M, m³/ha), and age (A).

Volume of tree (Vt, m³/tree) and forest volum (M, m³/ha) calculated:

V: Volume/tree and volume of area (M) total volume of area, unit (m³)^[9]. Volume of tree calculated: D_{1.3} (cross-sectional area $G = \pi/4 * D_{1.3}^2$) at 1.3 m, height (H_{vn}) and figure number 1.3 m (f_{1.3}) fomula:

$$V (m^3/tree) = \pi/4 * (D_{1.3})^2 * H_{vn} * f_{1.3} \quad (2)$$

V is standing trunk volume (m³/tree). D_{1.3} is diameter of trunk at 1.3 m. H_t is height to top of tree. f_{1.3} is figure number at 1.3 m (for plantation f_{1.3} = 0.5)^[10].

Average forest volume (M_{av}, m³/ha)

$$M_{av} (m^3/ha) = 10.000 * M_{SP}/S_{SP} \quad (3)$$

M_{SP} (Volume of Standard plot SP) is total volume of standard plots at age levels i, S_{SP} is total area of standard plots at age levels i.

Average forest density (N_{av}, tree/ha)

$$N (tree/ha) = 10,000 * N_{SP}/S_{SP} \quad (4)$$

N_{SP} is total trees of standard plots at age levels i.

2.3. Calculated Methods

Using Microsoft Excel and Statgraphics Centurion XVI statistical software. Excel spreadsheets are used to collect data, create tables and draw charts. Statgraphics Centurion XVI statistical software is used to calculate descriptive statistics and build growth functions^[11,12].

3. Results

3.1. Successful Restoration of Primary Forests into Secondary Forests

3.1.1. Step 1: Receiving a Resource from Wasteland and Regenerating Shrubs

Perspectives on primary forests and mangrove forest succession in Can Gio:

Successful restoration of primary forests into secondary forests must meet two principles: firstly, ensuring the biodiversity of plant communities and second is forest capital (**Figures 2 and 3**).

$$Fse = Bi + Fca$$

Figure 2 demonstrates the perspectives on biodiversity (Bi).

Table 2 shows the Can Gio mangrove forest area in 1977.

The Can Gio mangrove forest has about 40,000 ha^[13], 10 communities, a height of over 25 m and a diameter of 25–40 cm. The dominant species are Rhizophora, Sonneria, Avicennia and Aegiceras. In the 1950s–1960s, it was a highly biodiverse primary forest. Before 1977^[14], due to economic development, the forest was exploited and destroyed (**Table 2, Figures 2 and 3**). This area belongs to Ho Chi Minh City, with a population of over 14 million people. The environmental and climate change impacts on this most populous urban area in Vietnam have become a major concern for domestic and international organizations.

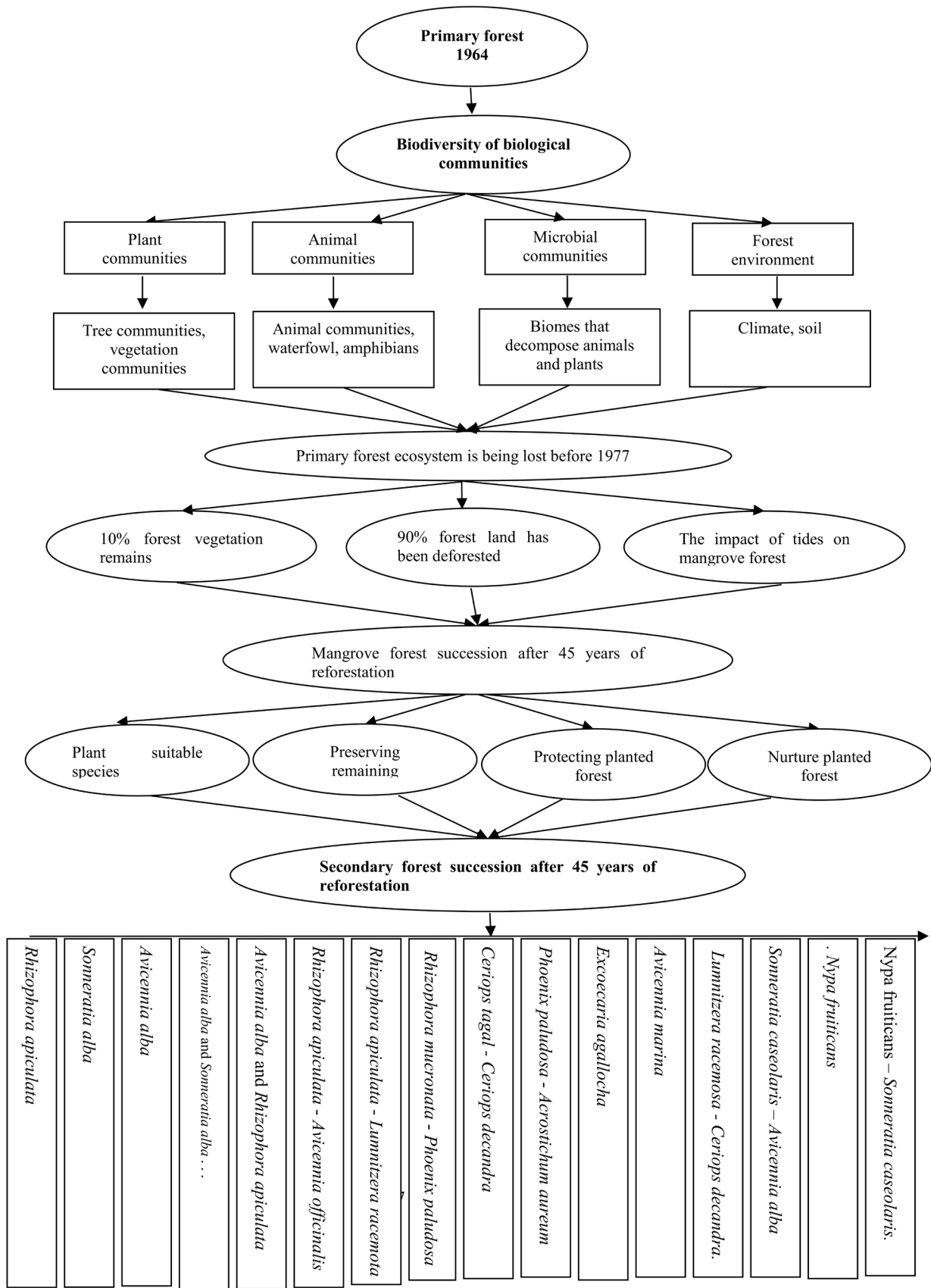


Figure 2. Secondary succession of mangrove forests in Can Gio after destruction before 1977.



Figure 3. The primary forest with high biodiversity exploited and destroyed by humans.

Table 2. Forest cover of Can Gio in 1977 ^[13].

Forest Status	Unit (hectare/ha)
Forest	
Natural forest	
Area of scattered shrubs	4500
Forest land (without forest)	
Total	35,286.53

3.1.2. Step 2: Surveying and Establishing a Plan for the Original Primary Forest

Building new ecological capital to restore forests to their original state requires time. **Figure 4** shows the perspectives on forest capital. The function Enc (Ecology of

new development capital) includes parameters such as remaining forest capital, land resources, plant habitat capital, and the ecosystem derived from the forest capital. Over time, reforestation, protection, restoration, and nurturing will create new forest capital.

$$Enc = Frc + Lc + Enc + Ecc \quad (5)$$

Newly established forests can follow three directions: firstly, the forest grows well, achieving a successful planting rate of over 85%; secondly, the forest achieves a success rate of less than 50%; and thirdly, the forest achieves a success rate of less than 15%. In the case of mangrove forests in Can Gio following the first approach, the forestation rate reaches over 85% (**Figure 5**).

The planting on the soil terrain (**Table 3** and **Figure 5**). In 2001 no more planting of *Rhizophora apiculata* ^[2]. Age classification of mangrove forest in Can Gio ^[6] age level is 5 years ^[2]. The years planting forest are 1977, 1982, 1987, 1992 and 1997 corresponding to the forest in 2022 the ages 25, 30, 35, 40 and 45 ^[15]. The initial planting density is 10.000 trees/ha ^[16].

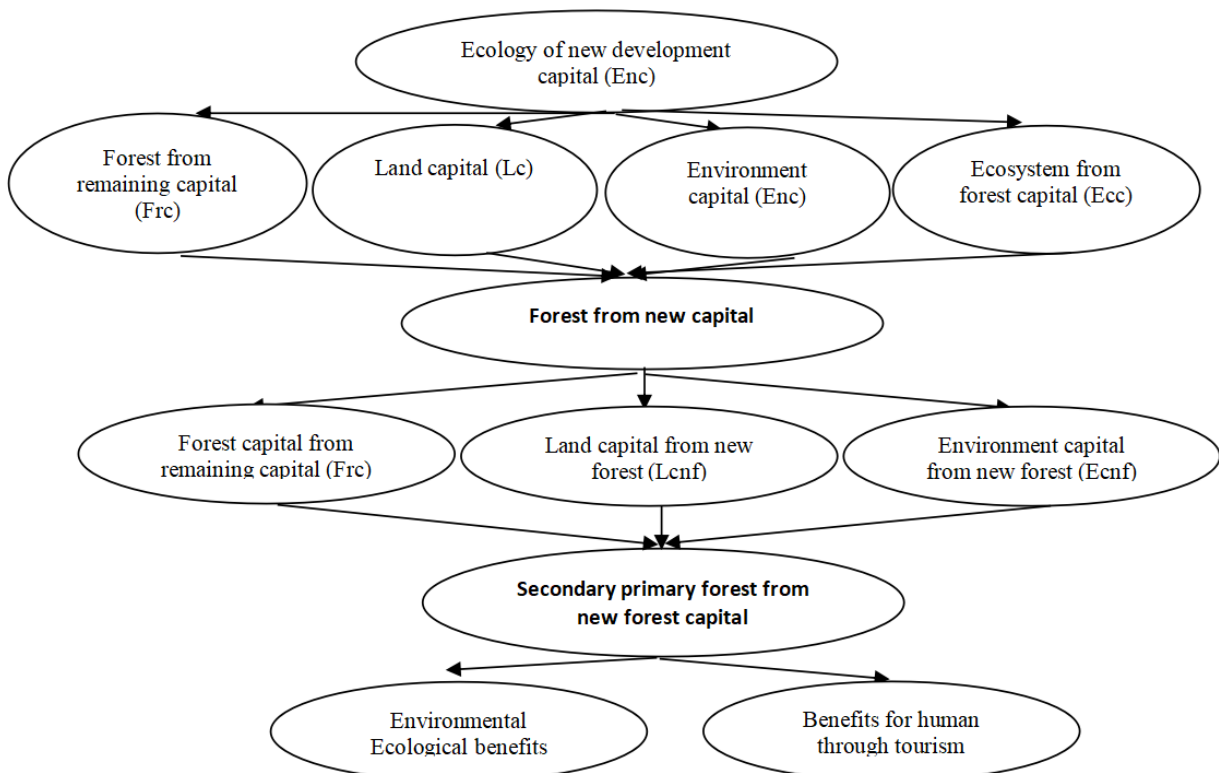


Figure 4. A successful plan for building forest resources into nature reserves from lost forest resources.



(a) Selecting species for reforestation.



(b) A forestation activities (photo: Le Duc Tuan)

Figure 5. Reforestation activities in devastated areas.

Note: Non-English text in **Figure 5b** indicates: photo Le Duc Tuan.

Table 3. Characteristics of Forestland after Deforestation for Dividing Low and High Terrain ^[13].

The Soil Terrain	Low Soil Terrain	High Soil Terrain
Tidal height (m)	0–2 m	>2 m
Flooding mode	Flooded by regular, medium and low tides	Flooded by mean, high and abnormally high tides
Number of floods/month	>40 times	<40 times
Number of floods/month	>10 days	<10 days
Soil (background position)	Mud, soft mud and tight mud	Soft clay, hard clay and solic soil
Food subsidence	>20 cm	0–20 cm

3.1.3. Step 3: Restoring the Forest's Current State Using Native Tree Species and Evaluating it through a Comparative Secondary Ecosystem

The area of mangrove forests in Can Gio has been restored.

The results is creation of secondary forest succession by replanting the adapted tree species *Rhizophora apiculata* and other species (**Table 4, Figures 6 and 7**) show *Rhizophora apiculata* ratio is 91.18%, *Eucalyptus camaldulensis* is 3.09%, *Sindora maritima* is 2.76%, *Nypa fru-*

iticans is 1.21%, other species as *Hibiscus tiliaceus*, *Bruguiera gymnorrhiza*, *Rhizophora mucronata*, *Lumnitzera racemosa*, *Cylocarpus granatum*, *Avicennia officinalis* from 0.08–0.44%. These results show *Rhizophora apiculata* is dominant species, The same study of growth dynamics and survival of mangroves (*Rhizophoraceae*) seedlings in Guang-guang. Mati City. Davao Oriental. Philippines ^[16]. But other species, although occupying a small area, contribute to the plant biodiversity in this secondary forest. Meanwhile in the Mangrove Forest Area of Sriminosari Village only *Avicennia marina* and *Avicennia apiculata* are 100% ^[17], Thus, Mangrove forest has high biodiversity.

Table 4. Area of Planted Forests of Various Tree Species in Can Gio in 2022.

Local Name	Scientific Name	Forest Cover (ha)	Ratio (%)
Duoc	<i>Rhizophora apiculata</i>	21,101.6	91.18
Bach dan	<i>Eucalyptus camaldulensis</i> Dehnh	715	3.09
Go bien (Da)	<i>Sindora maritima</i>	638.18	2.76
Dua nuoc	<i>Nypa fruiticans</i>	280.5	1.21
Tra	<i>Hibiscus tiliaceus</i> L	101.14	0.44
Vet	<i>Bruguiera gymnorrhiza</i> (L.) Lam	95.14	0.41
Dung	<i>Rhizophora mucronata</i>	68.4	0.29
Coc trang	<i>Lumnitzera racemosa</i>	50	0.22
Xu oi	<i>Cylocarpus granatum</i>	19.25	0.08
Mam den	<i>Avicennia officinalis</i>	18.5	0.08
Mixed species		55	0.24
Total		23,142.71	100



(a) Mangrove forest after reforestation.



(b) Plant biodiversity after forest reforestation.

Figure 6. Mangrove forests after successful planting and reforestation.



(a) Secondary forest succession after 45 years.



(b) *Sonneratia caseolaris* forest at river-sea estuaries.

Figure 7. Secondary forest succession after 45 years.

The secondary forest communities: Saltwater communities are (1) *Rhizophora apiculata*, (2) *Sonneratia alba*, (3) *Avicennia alba*, (4) *Avicennia alba* and *Sonneratia alba*, (5) *Avicennia alba* and *Rhizophora apiculata*, (6) *Rhizophora apiculata* and *Avicennia officinalis*, (7) *Rhizophora apiculata-Lumnitzera racemota-Ceriops decandra*, (8) *Rhizophora mucronata-Phoenix paludosa-Lumnitzera racemosa*, (9) *Ceriops tagal-Ceriops decandra*, (10) *Phoenix paludosa - Acrostichum aureum*, (11) *Excoecaria agallocha*, (12) *Avicennia marina*, (13) *Lumnitzera racemosa-Ceriops decandra*. Brackish water communities include: (1) *Sonneratia caseolaris-Avicennia alba*, (2) *Nypa*

fruiticans-Sonneratia caseolaris, (3) *Nypa fruiticans*. The Can Gio plant community, after forest restoration, was surveyed and found to consist of 13 mangrove communities and 3 brackish water communities. Compare in Lubuk Kertang, Langkat Regency, Indonesia have nine species is Can Gio is higher^[18].

Assessment of mangrove forest restoration in Can Gio shows that over 85% of the area has been restored in terms of forest cover, and 16 natural plant communities have been recreated. The assessment indicates that the restoration level is 85% of the original primary forest in terms of plant communities.

3.2. Mangrove Forest (*Rhizophora apiculata*) Growth Process after Reforestation

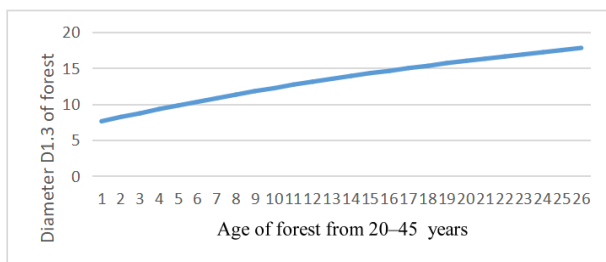
On terrain less than 2 m, the tree trunk diameter (D1.3 m) grows at 0.5 cm/year from age 21 to 29.4 cm/year from age 30 to 39, and 3 cm/year from age 40 to 44, compare in the Federated States of Micronesia (FSM) is 0.25 cm/year^[19]. Height growth decreases from 0.9 m to 0.5 m/year from age 20 to 25, from 0.4 m to 0.3 m/year from age 26 to 29, from 0.2 m to 0.1 m/year from age 30 to 36, and from age 37 to 44, growth is very low, decreasing from 0.1 m to 0 m/year, almost ceasing height growth. In terms of trunk volume, from age 20 to 44, the growth is 0.006 m³–0.009 m³/year. Volume growth of stem, from age 20 to 24, the growth volume decreases from 5.32 to 4.03 m³/year; from age 25 to 36, it decreases from 3.79 m³ to 2.07 m³/year; and from age 37 to 44, it decreases from 1.98 m³ to 1.47 m³/year, indicating a gradual decrease in volume over time from age 20 to 44 (**Figure 8**). Difference with study from a Mangrove Area in Samut Songkram Province, Thailand, plantation only for charcoal^[20].

Growth indicators in the terrain from 0 to 2 m show that D1.3 (**Figure 9a**) increases from age 20 to 32, then increases again until age 32 and gradually decreases at age 43. Height (**Figure 9b**) increases sharply from age 20 to 29, gradually decreases from age 31 to 39, then increases very slowly and stops growing from age 40 onwards. Volume of tree (**Figure 9c**) continues to increase until age 45 due to continued diameter growth and the forest yield (**Figure 9c**) increase, although there is some tree mortality, the rate is not high. Regarding tree trunk volume, annual growth ranges from 0.007 m³ to 0.009 m³/year from age 20 to 44, showing that volume growth continues steadily un-

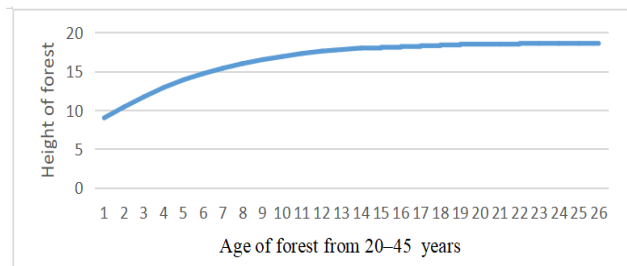
til age 44. Regarding timber volume per hectare, from age 20 to 22 it is 5.99 m³ down to 4.08 m³/year, from age 27 to 31 it grows from 3.85 m³ to 3.09 m³/year, and from age 32 to 40 it is 2.95 m³ to 2.03 m³/year, growing from 1.95 m³ down to 1.73 m³/year. This indicates that forest yield gradually decreases with age from 20 to 44 years per hectare/year. Modelling growth and primary production of the marine mangrove (*Rhizophora apiculata* BL) is target Can Gio to go^[21].

3.3. Comparison of Growth Indicators of Pkanted Forest after 45 Years (5-Year Age Class for Each Age Class)

Regarding the health rate of trees in the two types of terrain (**Table 5**), it shows that in low-lying terrain, the proportion of good-quality trees is high, ranging from 75.5% (age level IX, 45 years) to 88.2% (age level VI, 30 years). From age level VI onwards, the health of good trees gradually decreases. Average tree health ranges from 3.3% (age level VII, 35 years) to 21.7% (age level VIII, 40 years, IX, 45 years). The proportion of poor-quality trees is low in low-lying terrain. At age level VII, 35 years, the proportion of trees with poor health is 9.4%. High-lying terrain has a proportion of healthy trees ranging from 67.9% at age level IX, 45 years to 90.0% at age level V, 25 years. The percentage of healthy trees decreased from age level V, 25 years (90.0%) to age level IX, 45 years (67.9%). The average height of trees increased from age level V, 25 years (8.3%) to age level IX, 45 years (27.8%). The percentage of poor trees in this terrain is low. At age level VI, 35 years, the percentage of trees with poor health is 9.2%.

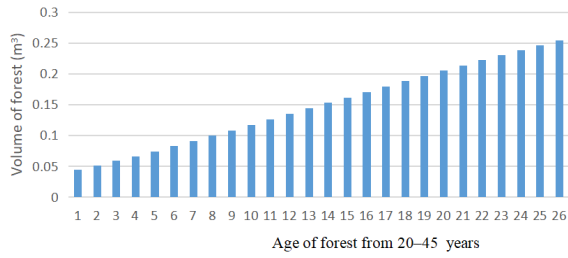


(a) Diameter of *Rhizophora apiculata* (D1.3 m) on 0–2 m of terrain.

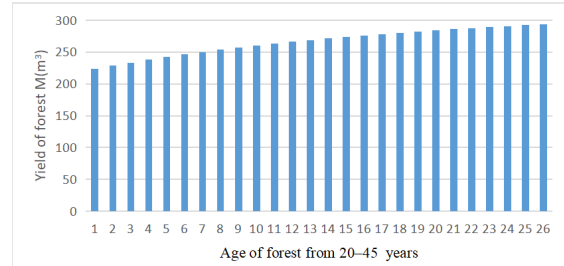


(b) Height of *Rhizophora apiculata* Ht (m) on 0–2 m of terrain.

Figure 8. Cont.

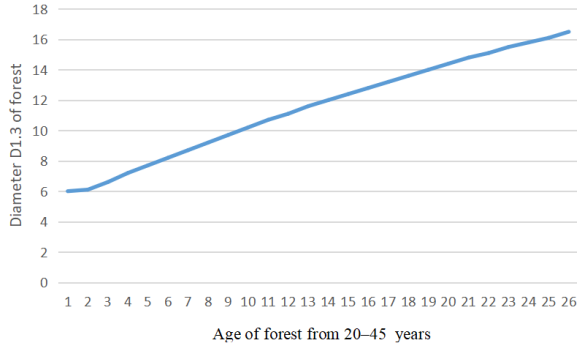


(c) Volume of *Rhizophora apiculata* tree V (m³) on 0–2 m of terrain.

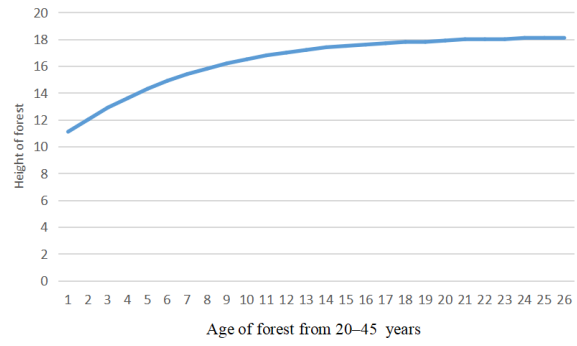


(d) Yield of *Rhizophora apiculata* forest M (m³) on 0–2 m of terrain.

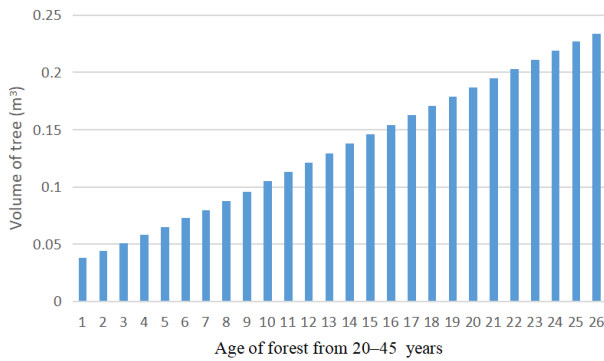
Figure 8. Growth indicators of *Rhizophora apiculata* forest on 0–2 m of terrain.



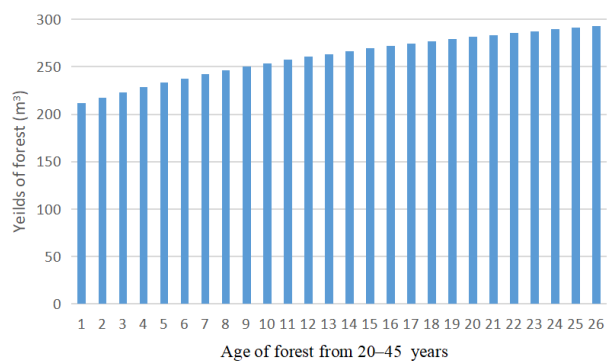
(a) Diameter of *Rhizophora apiculata* forest on <2 m of terrain.



(b) Height of *Rhizophora apiculata* forest on <2 m of terrain.



(c) Volume of *Rhizophora apiculata* tree on <2 m of terrain.



(d) Yield of *Rhizophora apiculata* forest on <2 m of terrain.

Figure 9. Growth indicators of *Rhizophora apiculata* forest on <2 m of terrain.

Table 5. Forest Quality Ratio at Two Soil Terrains.

Soil Terrain	Age Level	Health (%)		
		a	b	c
Low	V (25)	78.0	19.0	3.0
	VI (30)	88.2	9.2	2.6
	VII (35)	87.3	3.3	9.4
	VIII (40)	76.6	21.7	1.6
	IX (45)	75.5	21.7	2.7
High	V (25)	90.0	8.3	1.7
	VI (30)	81.3	9.6	9.2
	VII (35)	83.6	12.3	4.1
	VIII (40)	77.5	14.7	7.8
	IX (45)	67.9	27.8	4.3

Note: a,b,c: a is the best trees, b is normal trees,c is bad trees.

Table 6 summarizes the indicators of *Rhizophora* plantations.

Examine the two average diameter values between the two terrain types (**Table 7**). At age V (25 years), $p = 0.056 > 0.05$, there was no statistically significant difference between the two terrain types. At age VI (30 years), there was a difference with $p = 0.000001 < 0.05$, the diameter in the low-lying area with $D_{1.3av} = 13.3$ cm was

larger than the diameter in the high-lying area with $D_{1.3av} = 11.9$ cm. At age VII (35 years), there was no significant difference in diameter between the two terrain types with $p = 0.780 > 0.05$. At age VIII (40 years), there was no difference in diameter ($p = 0.158 > 0.05$). Similarly, at age IX, there was no difference ($p = 0.166 > 0.05$), the primary forest other study *Rhizophora apiculata* with diameter D1.3 can from 9 to 75.5 cm^[22].

Table 6. Growth Indicators of *Rhizophora* plantations on Two Types of Soil Terrain.

Soil Terrain	Age Level	$D_{1.3av}$ (cm)	H_{tav} (m)	V_{av} (m ³ /cây)	M (m ³ /tree)	N (tree/ha)
Low	V (25)	10.0	14.7	0.073	244.27	3.340
	VI (30)	13.3	17.3	0.135	273.04	2.027
	VII (35)	14.1	18.2	0.166	271.30	1.633
	VIII (40)	16.7	18.5	0.224	274.59	1.227
	IX (45)	17.6	18.7	0.247	303.23	1.227
High	V (25)	9.6	14.8	0.067	238.79	3.560
	VI (30)	11.9	17.1	0.113	256.12	2.273
	VII (35)	14.2	17.3	0.161	276.76	1.720
	VIII (40)	16.2	17.6	0.196	272.97	1.393
	IX (45)	17.0	18.5	0.231	299.39	1.293

Table 7. Comparison Table of Average Diameter Values in Two Types of Soil Terrain.

Age Level	$D_{1.3av}$ (cm)		Significance Level (5%)		
	Low	High	p	t -Calculate	t -Table
V (25)	10.0	9.6	0.056	1.91	1.96
VI (30)	13.3	11.9	0.000001	5.08	1.96
VII (35)	14.1	14.2	0.780	0.28	1.96
VIII (40)	16.7	16.2	0.158	1.42	1.96
IX (45)	17.6	17.0	0.166	1.39	1.96

Examine the two mean height values between low and high terrains (**Table 8**). At age V (25 years), there was no significant difference in height with $p = 0.551 > 0.05$. At age VI (30 years), there was no statistically significant difference with $p = 0.397 > 0.05$. At age VII (35 years),

height showed a statistically significant difference with $p = 0.00006 < 0.05$. At age VIII (40 years), this difference was significant with $p = 0.00007 < 0.05$. At age IX (45 years), there was no significant difference in height between the two types of locations with $p = 0.460 > 0.05$.

Table 8. Comparison Table of Average Height Values in Two Types of Soil Terrain.

Age Level	H_{vn} (m)		Significance Level (5%)		
	Low	High	p	t -Calculate	t -Table
V (25)	14.7	14.8	0.551	0.60	1.96
VI (30)	17.3	17.1	0.397	0.85	1.96
VII (35)	18.2	17.3	0.00006	4.04	1.96
VIII (40)	18.5	17.6	0.00007	4.02	1.96
IX (45)	18.7	18.5	0.460	0.74	1.96

Examine the two mean values between lowland and highland areas regarding tree trunk volume (Table 9). At age V (25 years), there was no significant difference with $p = 0.120 > 0.05$. At age VI (30 years), there was a statistically significant difference: lowland areas had a mean volume of $0.135 \text{ m}^3/\text{tree}$, which was greater than highland areas with $0.113 \text{ m}^3/\text{tree}$. At age VII

(35 years), there was no significant difference with $p = 0.663 > 0.05$. At age VIII (40 years), there was a significant difference: the tree trunk volume in lowland areas ($V = 0.224 \text{ m}^3/\text{tree}$) was greater than in highland areas ($V = 0.196 \text{ m}^3/\text{tree}$) with $p = 0.015 < 0.05$. At age group IX (45 years old), there was no difference with $p = 0.239 > 0.05$.

Table 9. Comparison Table of Average Values of Tree Trunk Volume in Two Types of Soil Terrain.

Age Level	V _{av} (m ³ /tree)		Significance Level (5%)		
	Low	High	p	t-Calculate	t-Table
V (25)	0.073	0.067	0.120	1.56	1.96
VI (30)	0.135	0.113	0.001	3.25	1.96
VII (35)	0.166	0.161	0.633	0.48	1.96
VIII (40)	0.224	0.196	0.015	2.43	1.96
IX (45)	0.247	0.231	0.239	1.18	1.96

When examining the two mean values between the two terrain types regarding forest density (Table 10), at age level V (25 years), there was no difference in forest density between the two terrains with $p = 0.754 > 0.05$. At age level VI (30 years), there was no statistically significant difference between the two terrains with $p = 0.641$. At age level VII (40 years), there was no differ-

ence in density between the two terrains with $p = 0.559 > 0.05$. At age level VIII (40 years), there was no difference in forest density between the two terrain types with $p = 0.746 > 0.05$. In 25 years Nt/ha is 3.340 and 3.560 trees per ha compare Indonesia is 3339.5–2856.3 trees/ha^[23], but in Sarawak is $65.55 \text{ m}^3/\text{ha}$ ^[24] and Ngoc Hien, Ca Mau, it is the same^[25].

Table 10. Comparison Table of Average Forest Density Values in Two Soil Terrains.

Age Level	N (tree/ha)		Significance Level (5%)		
	Low	High	p	t-Calculate	t-Table
V (25)	3.340	3.560	0.754	0.34	2.78
VI (30)	2.027	2.273	0.641	0.50	2.78
VII (35)	1.633	1.720	0.559	0.64	2.78
VIII (40)	1.227	1.393	0.496	0.75	2.78
IX (45)	1.227	1.293	0.746	0.35	2.78

Comparing the two mean values between the two terrain types regarding forest reserves (Table 11 and Figure 10), there was no statistically significant difference when considering the same age class between the two terrain types in terms of forest reserves: Age class V (25 years) with $p = 0.903 > 0.05$, Age class VI (30 years) with $p = 0.802 > 0.05$, Age class VII (35 years) with $p = 0.916 > 0.05$, Age class VIII (40 years) with

$p = 0.980 > 0.05$, and Age class IX (45 years) with $p = 0.945 > 0.05$. The yield of *Rhizophora apiculata* of Can Gio at 25 year is 244.27 m^3 and 238.27 m^3 compare Ben Tre from 133.62 m^3 – 171 m^3 ^[7], and in Samut Songkram Province, Thailand is $181.49 \text{ m}^3/\text{ha}$ ^[20], the results are similar with the study “Modelling growth and primary production of the marine mangrove (*Rhizophora apiculata* BL)”^[21].

Table 11. Comparison Table of Average Forest Reserve Values in Two Site Types.

Age Level	M (m ³ /ha)		Significance Level (5%)		
	Low	High	<i>p</i>	<i>t</i> -Calculate	<i>t</i> -Table
V (25)	244.27	238.79	0.930	0.09	2.78
VI (30)	273.04	256.12	0.802	0.29	2.78
VII (35)	271.30	276.76	0.916	0.11	2.78
VIII (40)	274.59	272.97	0.980	0.03	2.78
IX (45)	303.23	299.39	0.945	0.08	2.78



(a) Plantation grow slowly after 45 years.



(b) Old forest stem diseases and insect pests.

Figure 10. Secondary forest succession after 45 years of restoration and growth process of *Rhizophora apiculata* plantation.

4. Conclusions

The restoration of the Can Gio primary forest is considered successful due to its implementation in three steps:

- Step 1 involves identifying and restoring the ecosystem and plant communities of the former primary forest;
- Step 2 involves planting adapted tree species that are distributed across two types of terrain on alluvial plains: 0–2 m and <2 m;
- Step 3 involves evaluating the recovery of plant communities.

The results show the recovery of 13 saltwater plant communities and 3 brackish water communities in the Can Gio mangrove forest.

For individual of *Rhizophora apiculata*: The average diameter of the forest ($D_{1.3av}$) in both lowland and highland terrains increases gradually with age, similar to the average height of the forest (H_{lav}), which increases slowly

with age from age level V(25) to age level IX. The forest volume growth (V_{av}) in both lowland and highland terrains increases gradually from age level V(25) to VIII (40) and decreases gradually from age level VIII (40) to IX (45).

For population of *Rhizophora apiculata*: The growth in volume of M_{av} forest in both lowland and highland terrains is concentrated in a gradual decrease from age level V (25) to age level IX (45) in the study area. Highland terrain factors affect the average diameter, height and volume of forest at age levels VI, VII and VIII. In terms of forest density and volume, there are generally significant differences between lowland and highland locations. We can create a table to look up the $D_{1.3}$, H_t , V_{av} and M_{av} data by age, helping us to look up the table to deduce each index by age of this tree species.

Comparing the two terrains, the tree trunk diameter $D_{1.3}$ m, height H_t , and trunk volume V_t show more favorable growth on the low terrain (0–2 m) than on terrain higher than 2m. Regarding tree density, the density is low-

er on the low terrain (0–2 m) than on terrain higher than 2 m. In terms of timber volume, the low terrain (0–2 m) has a higher volume than the terrain higher than 2m.

Author Contributions

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Not applicable. All studies only study plants and soil. It is not related to humans; it only helps the community and government to develop the economy.

Data Availability Statement

These databases are elaborated by authors. Thus, we used to study and for our article, published in the journal, can be shared by the authors' group.

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Conflicts of Interest

The authors declare no conflict of interest.

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