Title	沖縄島北部の亜熱帯照葉樹林における帯状伐採施業7年後の二次遷移
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Seven-year succession of a subtropical laurel forest following strip clear-cutting on Okinawa Island

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Abstract: The mortality of stumps and growth of a secondary forest in cut area seven years post strip clear-cutting in a natural subtropical laurel forest on Okinawa Island were studied. The results showed the mortality rate of stumps was 34.7%, which was higher than those in a similar secondary forest at the first and the fifth year after clear-cutting (13.2, 20.2%, respectively) in nearby site, confirming that the mortality rate of stumps increased with years in a certain years. In contrast to dead of one-thirds of stumps nearly, majority of stumps remained alive, of which, 12.8% of the stumps were remained initial figure, 42.6% of them partly decaying and 9.9% of them invisible with living sprout. The secondary forest was consisted of a total of 74 woody species, of which, 49 and 69 species, respectively, were found in sprout- and seedling-origins, greater than that in the primary forest (53 species) before strip clear-cutting. The primary dominant species, *Castanopsis sieboldii,* still dominated the secondary forest. The mean stem number of seedling origin stems by plot was significant ($p < 0.05$) higher than that of sprouting origin ones. However, no significant differences found for the mean basal area by plot between two kinds of stem origins. Seedling stem number in DBH group < 4.0cm had higher values than those for sprout's, while sprout origin stems in basal area were roughly seven-fold more than that for seedling's in DBH group > 4.0cm. The results indicated that the seedling stems shared the understorey and sprout-origin stems shared the crown canopy in the early succession stage. The secondary forest was dominated by sprout stems rather than seedling-origin ones. The great of woody species with abundant of sprout- and seedling-origin stems suggested the secondary forest seven years after strip clear-cutting occurred in a progressive succession.

Keywords: subtropical laurel forest, strip clear-cutting, mortality of stumps, sprout and seedling stems, cut area

Introduction

The study of natural regeneration is one of the most interesting topics in forest management.[1-4] Much of what we have learned about the dynamics of forest secondary succession to disturbance comes from studies of forest regeneration following clear-cutting for deciduous or coniferous forests[5-9], few studies focused on the sprouting natural regeneration of laurel forest following strip clear-cutting.[10]

Sprouts play an important role in stand regeneration because they maintain populations of some species as a form of direct regeneration during the initial successional stages following sever cutting. Sprouts can grow quickly because of their already established and functioning root system. Thus, sprouting is an efficient way for woody plants to recover lost biomass during disturbances. The degree of sprouting formation may depend on the interaction between the frequency and severity of the disturbances.[11,12] Sprout formation may also vary among species and between plants of different sizes. In contrast to sprout trees, seedlings may coexist at the cutting district at meantime.[13,14] How about the growth and succession for both sprouts and

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seedlings in the early stage after strip clear-cutting? We know not enough about them.

Subtropical laurel forest dominated by *Castanopsis sieboldii* is widely distributed in the northern part of the Okinawa Island.[15] Restoration of such forests through natural regeneration to protect the unique natural island landscape in Ryukyu Islands has become an important study project. To explore appropriate natural regeneration mode of these subtropical laurel forests, several experimental methods of natural restoration management, such as clear-cutting, selective cutting and strip clear-cutting, have been conducted as a harmonization between utilization and conservation of the forest in Okinawa.[13,14,16-20] In the previous study, we reported the surviving states of primary trees in residual areas seven years after strip clear-cutting.[10] In this paper we focus on woody species in cut area for both sprout- and seedling-origin trees, especially for decay states of stumps and early response of the regenerating trees. To test these questions, the data in the present study within the secondary forest were initially subjected to either sprout alone or seedling origin.

Methods

1. Site description

The study was conducted in a subtropical laurel forest at Yona Field, Subtropical Field Science Center, Faculty of Agriculture, University of the Ryukyus, located in the northern part of Okinawa Island in Japan (26° 45' 30″ N and 128° 05′ E). The region is characterized by a maritime subtropical climate and abundant rainfall throughout the year. Typhoons frequently occur from July to October, bringing high rainfall and strong winds to the island. The rainfall is about 2,750mm per year. The mean annual temperature was 21.8℃. Prior to strip clear-cutting, the study site (3,600 m^2 in total) was covered with a natural laurel forest dominated by *C. sieboldii*. The compositions of main tree species, density and basal area before strip clear-cutting in the cut area were shown in Table 1. The trees in strip cut area in the sampling plots (500 m^2) consisted of 53 tree species and a total of 891 tree stems (17,820ha^{-1})with height equal to or over 1.2m. The maximum DBH (diameter at breast height) in the plots was 61.0cm, and the highest tree reached 12.0m. In addition, the altitude ranges from 320m to 340m a.s.l.

2. Experimental design

Four 20m×10m plots named A, B, C, D, and two 10m × 10m plots named E, F were established in sequence at almost same contour line in a natural forest in January 1995. The four 20m×10m plots were further divided into two subplots (10m×10m, in size) named A_1, A_2, and so on. For the convenience of investigation, all 10m×10m subplots were sub-divided into 25 cells (2m×2m each). In February 1995, strip clear-cutting was carried out; the trees in plots A, C, E were felled at the base of tree about 20cm height above the ground, while the trees in plots B, D and F remained. After above treatments the forest land was laid in natural state without other manmade disturbance.

The current stump states were checked. The stump states in the cut area were divided into 4 types as shown in Fig. 1. In addition, the woody plants enumerated in the survey were nominated according to Hatusima.[21]

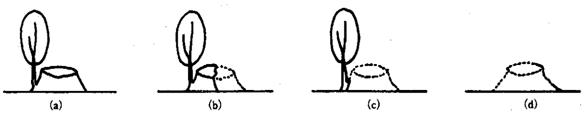

Fig. 1. Decay states of stumps. (a) The stump was remained original figure with living sprout; (b) the stump was decaying partly with living sprout; (c) the stump could not been seen with living sprout; (d) the stump was dead without living sprout.

Table 1. The main woody species in experimental plots in cut area before strip clear-cutting.*

Species	Mean DBH	Mean height	Stem density		Basal area	
	(cm)	(m)	(stems ha^{-1})	%	m^2ha^{-1}	%
Castanopsis sieboldii (Itajii)	14.7	6.1	760	4.3	26.0	42.1
Schefflera octophylla (Fukanoki)	9.4	5.4	380	2.1	4.3	7.0
Distylium racemosum (Isunoki)	2.9	3.2	3,160	17.7	4.1	6.6
Elaeocarpus sylvestris (Horutonoki)	10.6	5.2	160	0.9	3.6	5.8
Lithocarpus edulis (Matebashii)	9.4	5.1	220	1.2	2.4	3.9
Schima wallichii ssp. liukiuensis (Iju)	13.4	6.6	100	0.6	2.3	3.7
Persea thunbergii (Tabunoki)	6.7	5.6	380	2.1	2.2	3.6
Rhus succedanea (Hazenoki)	18.9	9.3	60	0.3	1.7	2.8
Camellia lutchuensis (Himesazanka)	5.7	3.9	460	2.6	1.6	2.6
Ardisia quinquegona (Shishiakuchi)	1.1	2	4,340	24.4	0.6	1.0
Other 43 species	3.1	3.0	7,800	43.8	12.9	20.9
Total			17,820	100	61.7	100

* : Species are listed by basal area.

3. Data collection and analysis

Before the strip clear-cutting in January 1995, a tree census was conducted. All woody species with height equal to or higher than 1.2m in the study plots were recorded with species name, tree height, DBH. The permanent number was tagged on the tree at the base. In the present study, a tree census was performed in December 2002. All trees equal to or taller than 1.0m in height in cut plots A, C, E, were recorded by species name, tree height, DBH (for trees higher than 1.3m), and current decay states of all the primary stumps were checked as well. Statistical differences of mean stem number and mean basal area by plots between sprout and seedling origins were examined by a non-parametric analysis (Wilcoxon Sign Ranks Test).

Results

1. Mortality rate of stumps

Fig. 2 showed the decay states of tree stumps seven years post strip clear-cutting in the study plots A, C and E. Type "b" had the highest value (380 stems /$500m^2$) in all four types, while type "c" had the lowest one (88 stems/$500m^2$). In general, most of the stumps (65.3%) were living. Of which, 12.8% of all the stumps (type "a") were remained initial figure without obvious decay, 42.6% of them (type "b") partly decaying, and 9.9% of them (type "c") invisible, but with living sprout. In contrary to abovementioned living stumps 34.7% of the stumps were dead (type "d") without any living sprout.

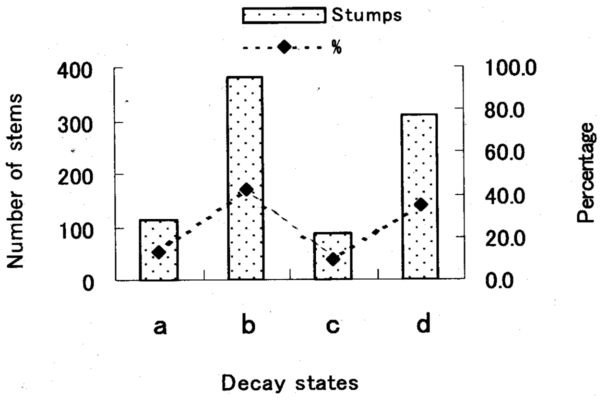

Fig. 2 Distribution of decay states of stumps in cut area seven years after strip clear-cutting.

2. Growth of the secondary forest

1) Changes by DBH

The mean stem numbers ($100m^2$) for seedling-origin stems in the sampling cut plots was 512.0 stems (51,200 stems ha^{-1}), and this value was significantly ($p < 0.05$) higher than the mean of 293.6 (29,360 stems ha^{-1}) for the sprout-origin ones (Fig.3). The stem frequency distribution by DBH for both sprout and seedling origin stems showed a typical "L" distribution (Fig. 4). Seedling origin stems had higher values in DBH group <4.0cm than that of sprout ones, and reverse situation occurred for DBH group> 4.0cm.

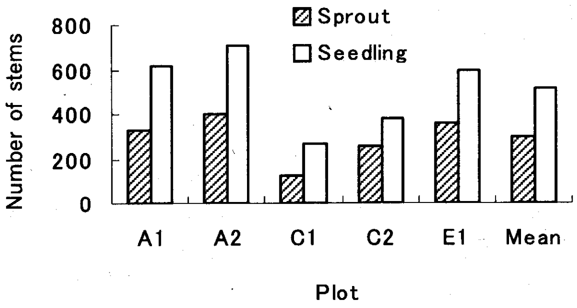

Fig. 3. Distribution of stems by plots in cut area for both sprout- and seedling-origin stems.

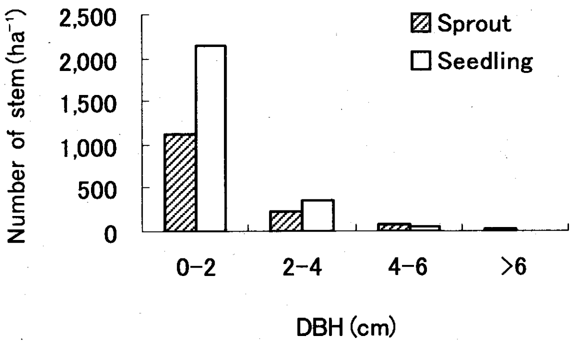

Fig. 4 Distribution of stem density by DBH in cut area seven years after strip clear-cutting.

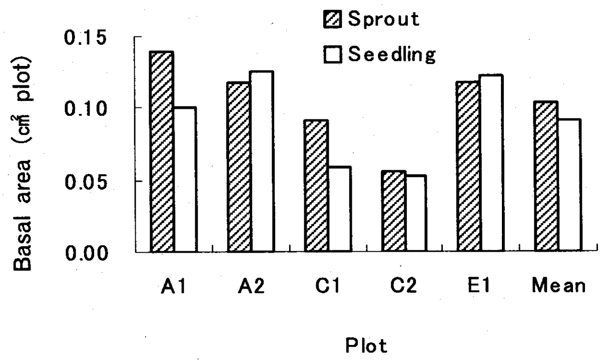

Fig. 5 Basal area by plot in cut area seven years after strip clear-cutting.

The mean basal area by plot ($100m^2$) was $0.10m^2$ ($10.43m^2$ ha^{-1}) and $0.092m^2$ ($9.16m^2$ ha^{-1}), respectively, for sprout- and seedling-origin stems (Fig. 5), no significant difference found between the two kinds of stems ($p >$ 0.05). The distribution of basal area by DBH showed DBH groups < 4.0cm seedlings had higher values than that for sprout ones (Fig. 6). In higher DBH group (>

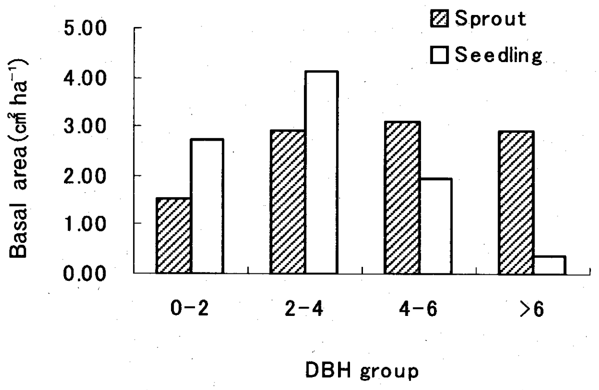

Fig. 6 Distribution of the basal areas by DBH group in cut area seven years after strip clear-cutting.

4.0cm), the reverse situate occurred, especially for DBH group > 6.0cm, sprout stems in basal area were roughly seven times more than that for seedling ones.

2) Changes by species

The stem density and basal area of main tree species either in sprout or seedling origin stems were showed in Table 2. The sprout origin stems were consisted of 49 species, while 69 species found in seedling stems. A total of 74 woody species were found in the whole regenerating forest in cut areas.

The tree species ranked the highest stem density differed between sprout and seedling origin stems. For the species with stem density $\geq$ 1,000 stems ha^{-1}, 3 species, namely *Ardisia quinquegona, C. sieboldii* and *Vibumum japonicum,* were found for sprout origin stems, while 10 species found for seedling origin ones. Especially, *Glochidion acuminatum, A. quinquegona* and *Styrax japonicus* ranked the highest values by turn with stem density $\geq$ 3,500 stems ha^{-1}. From the basal area for species over 2 $\times 10^{-1}$ m^2 ha^{-1}, *C. sieboldii* (2.71 m^2 ha^{-1}), *Lithocarpus edulis* (0.77m^{2}ha^{-1}) and *Schefflera octophylla* (0.76m^{2}ha^{-1}) ranked the highest values followed by other 10 species for sprout origin stems, whereas 8 species were present for seedling origin ones. Among these seedling stems, *Diospyros morrisiana, G. acuminatum Rhus succedanea* and *S. japonicus* had the highest basal area by turn. The species with high stem density and low basal area, were *A. quinquegona* and *V. japonicum* in sprout origin stems, *A. quinquegona* in seedling origin ones. Abundant of *A. quinquegona* with low basal area indicated that the small DBH stems had high frequency in the regenerating forest.

In addition, the primary dominant species *C. sieboldii* had roughly same stem density for sprout and seedling origin stems among 2,000~2,200 stems ha^{-1}, but sprout origin stems was roughly 7-fold that of the seedling ones, indicating that the regenerating forest was dominated by *C. sieboldii* from sprout origin stems rather than seedling ones. However, some seedling

Table 2. Stem density and basal area of the main species in the regenerating forest in cut area for the basal area higher than 2×10-1m2 ha-1 either in sprout- or seedling-origins.

Species	Sprout origin		Seedling origin	
	Stem density (ha^{-1})	Basal area (m^{2}ha^{-1})	Stem density (ha^{-1})	Basal area (m^{2}ha^{-1})
Castanopsis sieboldii (Itajii)	2,020	2.71	2,200	0.39
Lithocarpus edulis (Matebashii)	800	0.77	500	0.071
Schefflera octophylla (Fukanoki)	780	0.76	520	0.19
Diospyros morrisiana (Tokiwakaki)	480	0.74	2,440	1.72
Rhus succedanea (Hazenoki)	460	0.66	2,340	0.94
Elaeocarpus sylvestris (Horutonoki)	180	0.56	2,620	0.14
Wendlandia formosana (Akamizuki)	220	0.54	460	0.31
Persea thunbergii (Tabunoki)	980	0.50	1,040	0.17
Elaeocarpus japonicus (Kobanmochi)	320	0.39	440	0.15
Ardisia quinquegona (Shishiakuchi)	5,240	0.37	4,400	0.17
Styrax japonicus (Egonoki)	320	0.24	3,500	0.85
Vibumum japonicum (Hakusanboku)	1,080	0.24	780	0.11
Schima wallichii ssp. liukiuensis (Iju)	180	0.23	1,280	0.61
Glochidion acuminatum (Urajinokankonoki)			8,100	1.54
Dephniphyllum glaucescens ssp. Teijsmannii (Himeyuzuriha)	360	0.18	1,740	0.28
Other species*	15,940	1.55	18,840	1.53
Total	29,360	10.43	51,200	9.16

* : 35 species for sprout-origin and 54 species for seedling-origin.

origin trees, such as *D. morrisiana, G. acuminatum* and *R. succedanea* also had high basal area, indicating that these species also grew fast in the early stage after strip clear-cutting.

Discussion

In the previous studies, we found the mortality rates of stumps by clear-cutting at the first year and the fifth year were 13.2 and 20.2%, respectively, for the similar laurel forest nearby.[13,22] In the present study, the mortality rate after seven-year strip clear-cutting was 34.7%, higher than those abovementioned. Consideration of both clear-cutting and strip clear-cutting in the nearby stands, the consequence of mortality rates of stumps is: 7 th year (strip clear-cutting) > 5 th year (clear-cutting) > first year (clear-cutting). This strongly suggested in a certain years the mortality rate of stumps increased with years. In fact, mortality rate of stump is associated with many factors, such as nutrient space, period after cutting, tree species and ages of stump.[23-25]. In this study, the reasons of high mortality rate were probably the effects of nutrient space competition. The stem density was over 80,000 stems ha^{-1}, which was far more than that (17,820 stems ha^{-1}) before strip clear-cutting (Table 1 and 2). We deduced that some of stumps would die in the recent future, and the mortality rate may increase somewhat.

The seedling origin stems had higher stem numbers in DBH group < 4.0cm than that of sprout ones (Fig. 4), but the reverse situation occurred for DBH group > 4.0cm, especially for DBH group > 6.0cm, sprout origin stems in basal area were roughly seven times more than that for seedling ones (Fig. 6), suggesting that the canopy stems of the regenerating forest were mainly from sprout origin stems, and that the regenerating forest was dominated by sprout stems rather than seedling ones. Therefore, we concluded the seedling stems shared the understorey and sprout-origin stems shared the canopy in the secondary forest after seven-year strip clear-cutting. Moreover, the total basal area including both sprout and seedling stems was still low (Table 2), which was correspond of 35.6 % of that for mean basal area (55 m^{2}ha^{-1}) in the same kind forest in Okinawa[26], although the stem density was higher than 80,000 stems ha^{-1}. It could be concluded that the space competition for these stems would be still severe and most of stems would wither following the increases of basal area by years.

The sprout- and seedling-origin stems were consisted of 49 and 69 species, respectively, with a total of 74 species in the cut plots, higher than that (53 species) in the primary forest (Table 1 and 2), indicating the tree species in the early succession stage after strip clear-cutting increased. Connell[27] also found the secondary forests at middle-successional stages had more species than old-growth forests in tropical rainforest because secondary forests contain both pioneer and climax species. Wu et al[14] also found the similar result for a similar natural forest nearby, that the woody species in the regenerating forest increased five years after clear-cutting (62 and 81 species, respectively). The results demonstrated that the number of species of laurel forest after cutting in Okinawa increased in the early succession stage.

In the present study, *G. acuminatum,* a pioneer species, was abundantly present in the regenerating forest, which ranked the highest stem density in the regenerating forest (8,100 stems ha^{-1}) and shared the second highest value for basal area among the seedling-origin stems. Shinzato et al[17,18] reported that the pioneer species decrease by years after seven and thirteen year's clear-cutting for a similar laurel forest on Iriomote Island. Abundant exist of pioneer species suggested the secondary succession was in the beginning stage.

In conclusion, the high stem density and low basal area with abundant pioneer species suggested that the secondary succession 7 years after strip clear-cutting in cut area was still in the beginning stage. The distribution of stem density and basal area by DBH showed that the regenerating forest seven years after strip clear-cutting was dominated by sprout origin stems, and that sprout stems shared the canopy level. The high stem density also suggested the space competition for these stems would be still severe by years, and that some of stumps would die following the further succession of the forest.

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* : The titles are tentative translations from Japanese or Chinese titles by the authors of this paper.

沖縄島北部の亜熱帯照葉樹林における帯状伐採施業７年後の二次遷移

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キーワード：亜熱帯照葉樹林，帯状伐採施業，根株の枯死率，萌芽と実生，伐採区

要　約

本論文は沖縄の亜熱帯照葉樹林地帯において，天然更新を基盤とする各種天然林施業法に関する研究の一環をなすものである。帯状伐採施業は1994年実行され、保残区残存木の報告[10]に引き続き施業７年後の伐採区について調査した。試験林設定時の伐採区は伐採樹種53種、891株で、今回は根株（伐採株）の腐朽状態と萌芽幹、実生幹、新規発生木を樹高1.0m以上の全出現個体について毎木調査を行った。根株の枯死率（腐朽状態-ｄ-）は34.7％で，施業試験地が隣接する皆伐施業林の一年後、５年後の枯死率より高くなり，根株枯死率は伐採経年に伴って増大傾向を示した。根株の生育状況は約１/３の完全腐朽（枯死）に対して，多数の根株が生存あるいは萌芽幹を発生しており，そのうち根株の12.8％が萌芽幹発生・原型保持（腐朽状態-a-）、42.6％が萌芽幹発生・部分腐朽（b）、9.9％が萌芽茎発生・完全腐朽（ｃ）であった。施業７年後の二次林の樹種は74種で、そのうち49種が萌芽由来、69種が実生由来となり、伐採前林分（天然林）の53種より増加していた。萌芽力が強い天然林優占種のイタジイは、二次林途中相でも優占していた。実生由来と萌芽由来の間で、平均樹幹密度は実生由来が萌芽由来より高く有意差がみられたが、基底面積は有意差がなかった。胸高直径４cm以下の樹幹密度と基底面積は実生由来が萌芽由来より高く、胸高直径４cm以上の基底面積は萌芽由来が実生由来より高い値を示し、早期の二次林途中相では実生由来の多数個体が下層に出現し、萌芽由来が上層を占めていた。天然林伐採後、先駆樹種が侵入し樹種増加を伴うが、天然林構成種の萌芽由来と実生由来の発生がみられ、帯状伐採施業７年後の再生林は進行遷移に属することが示唆された。