沖縄の照葉樹林における帯状伐採施業7年後の保残区残存木の生育状態

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Surviving States of Primary Trees in Residual Areas Seven Years after Strip Clear-cutting in a Natural Laurel Forest in Okinawa, Japan

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Abstract: The effect of strip clear-cutting on surviving states of the primary trees 7 years post-cut in a subtropical laurel forest in Okinawa was studied. In the 3,600 m^2 study area, six permanent plots named A to F were established by sequence in January 1995. A tree census was conducted; all trees with height equal to or higher than 1.2 m in the study plots were numbered and recorded with species name, height, and diameter at breast height (DBH). Strip clear-cutting was conducted after the tree census in February; the trees in plots A, C, E were clear-felled at the base at 20 cm height above the ground, versus the other trees in plots B, D and F, which remained. In the present study, a new tree census was performed in December 2002. The primary trees consisted of 51 tree species 550 tree stems in plots B, D and F were checked. Examined and measures were the surviving state, DBH and height. The current state of the primary trees was divided into seven types. The results showed the majority of stems (64.7%) remained in regular state without obvious damage, while 35.3% of them were in disturbance, i.e. 15.8% of them were dead, 12.9 % of them were living in standing state with breakdown at treetop or with withered tops, and 6.6% of them were living in falling state. The surviving states of primary trees differed by DBHs, life forms and tree species. The smallest DBH group (1-2 cm) had the highest mortality rate, versus the big DBH group (>12 cm) which had the highest rate of breakdown at treetop. *Ardisia quinquegona,* a kind of nanophanerophyte species, had the majority of the dead stems, while the dominant species, *Castanopsis sieboldii,* had the low mortality (6.3%), with most stems (71.9%) in regular state.

Key words: strip clear-cutting, surviving state of primary tree, seven types of trees, subtropical laurel forest, natural regeneration

Introduction

Laurel forest dominated by *Castanopsis sieboldii* is widely distributed in the northern part of Okinawa Island, Japan.[1-2] Unfortunately, this type of forest had largely been destroyed during the Second World War, and has been deformed by excessive cutting and land use in recent decades[3]. Thus, great concerns regarding harmonization between utilization and conservation of this kind forest have been raised. Natural regeneration is regarded as the basic means of regeneration for natural forest in Okinawa.[4] To explore the feasible regenerating methods related to this kind of laurel forest, several field experiment utilizing measures including clear-cutting, selective cutting and strip clear-cutting, have been carried out by our research group.[5-9] In this paper, we examine the strip clear-cutting system 7 years after such a technique was tried. Since the strip-cutting system is relatively new, and the surviving state of primary trees after strip clear-cutting remains unclear in Okinawa, the objectives of this study were to (1) check the states of the primary trees by diameter breast height (DBH); (2) probe into the surviving states of the primary trees for different life forms and (3) investigate the surviving states of the primary trees changed by tree species 7 years after strip clear-cutting.

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Study Site and Methods

1. Study site

The study was carried out 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 rainfall is about 2,750 mm per year. The mean annual temperature is 21.8℃. The altitude ranges from 320 m to 340 m a.s.l. 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.

Prior to strip clear-cutting, the site was dominated by C. *sieboldii,* which shared 64.7% of the total stand volume. The composition of the site, including main tree species, density and basal area before strip clear-cutting is shown in Table 1. The trees in residual plots consisted of 51 tree species, 550 tree stems with height≧1.2 m. The maximum DBH in the plots was 96.0cm, and the highest tree reached 12.0 m. The distribution of the primary trees varied by DBH shows a typical "L" type according to the database (Fig. 1). In addition, the total designed area for this study is 3,600 m^2.

2. Methods

Four 20m×10m plots named A, B, C, and D, and two 10m×10m plots named E and F were established in sequence at almost the 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 A1, A2, and so on. For the convenience of investigation, the 10m×10m plots were sub-divided into 25 cells (2m×2m each). Before the strip clear-cutting, a tree census was conducted. All trees with height equal to or higher than 1.2 m in the study plots were recorded including species name, height and DBH. A permanent number was tagged on the tree at

Table 1. The main trees in experimental plots at residual area before strip clear-cutting in a natural evergreen broad-leaved forest.

Species	Mean DBH	Mean height	Density		BA	
	cm	m	stems ha^{-1}	%	m^2ha^{-1}	%
Castanopsis sieboldii (Itajii)	21.9	7.0	640	5.8	50.8	64.7
Distylium racemosum (Isunoki)	3.5	3.6	2,600	23.6	5.7	7.3
Diospyros morrisiana (Tokiwagaki)	15.9	8.8	100	0.9	2.4	3.0
Ilex goshiensis (Tsugemochi)	12.4	4.3	80	0.7	2.2	2.8
Schefflera octophylla (Fukanoki)	7.5	4.8	300	2.7	2.1	2.7
Elaeocarpus sylvestris (Horutonoki)	10.8	5.9	80	0.7	1.3	1.7
Styrax japonicus (Egonoki)	5.1	4.4	240	2.2	1.3	1.7
Camellia lutchuensis (Himesazanka)	5.2	4.3	460	4.2	1.3	1.6
Elaeocarpus japonicus (Kobanmochi)	9.5	7.2	120	1.1	0.9	1.2
Ardisia quinquegona (Shshiakuchi)	1.4	2.3	3,000	27.3	0.5	0.7
Randia canthioides (Shimamisaonoki)	2.2	2.7	460	4.2	0.3	0.4
Other 40 species	4.41	3.7	2,920	26.5	9.6	12.2
Total			11,000	100	78.6	100

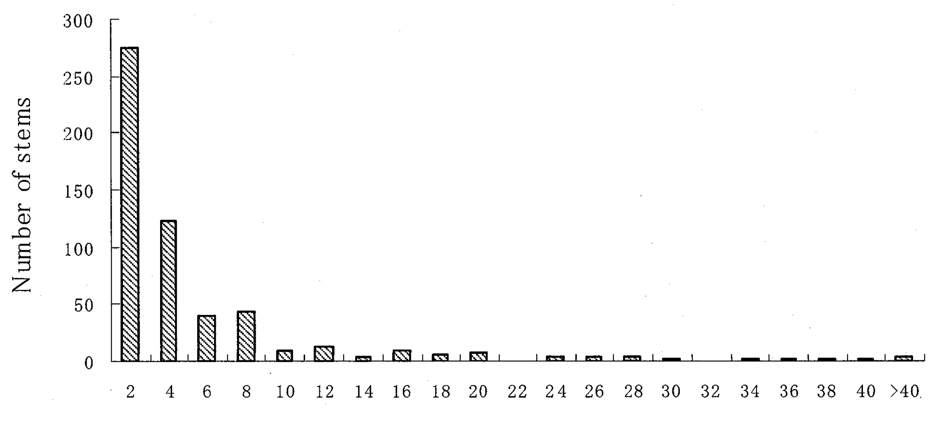

Fig. 1. Distribution of the primary trees by DBH in residual plots for a natural laurel forest. The stem numbers by DBH showed a typical "L"distribution.

the base. In February 1995, strip clear-cutting was conducted; the trees in plots A, C, E were felled at the base at 20 cm height above the ground, while the trees in plots B, D and F remained. In the present study, a tree census was performed in December 2002. All trees equal to or taller than 1.0 m, including all primary stems in plots B, D and F, were recorded by species name, height, DBH (for trees higher than 1.3 m) and current surviving states.

The current surviving states of primary trees were divided into 7 types as shown in Fig 2. The life-form spectra were divided into 4 types, namely mega (MM), mesophanerophyte (M), microphanerophyte (NM) and nanophanerophyte (N) according to Flora of the Ryukyus.[10)]

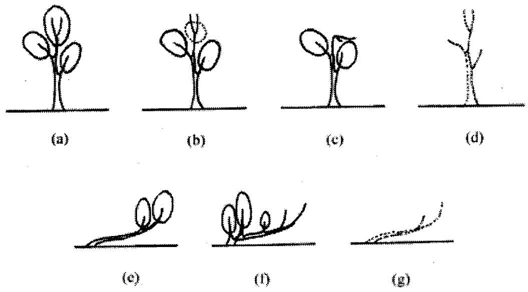

Fig. 2. Surviving state of the primary trees 7 years after strip clear-cutting. a) living in regular state. b) living with withered treetop; c) living with breakdown at treetop; d) dead in standing state; e) living in fallen state; f) fallen but with living sprout; g) dead in falling state.

Results

The frequency of the primary trees for different surviving states is shown in Fig. 3. Seven years after strip clear-cutting, the majority of stems (type "a", 64.7%) remained in regular state without obvious damage. 15.1% of them ("g") were dead in fallen state, while 0.7% of them ("d") were dead in standing state, resulting in a mortality rate of 15.8% ("d" +"g"). The state with breakdown at treetop shared the value 9.1% ("c"), versus 3.8% of the trees ("b") which lived with withered treetops, showing that 12.9% of the trees ("b" +"c") were living in standing state. Trees living in a fallen state hit 6.6% of the trees ("e"+ "f"). Of these, 3.5% lived in fallen ("e"), while 3.1% of them ("f") in a fallen state but with living sprouts. These disturbed stems made up 35.3% of the total stems in the residual plots.

1. Surviving states of primary trees by DBH

The DBH group of 1-2 cm had the highest stem number among the surviving states of the primary trees except type "d" (Fig. 4a). Along with the increases in DBH, the decreased trends in stem number were found for the surviving

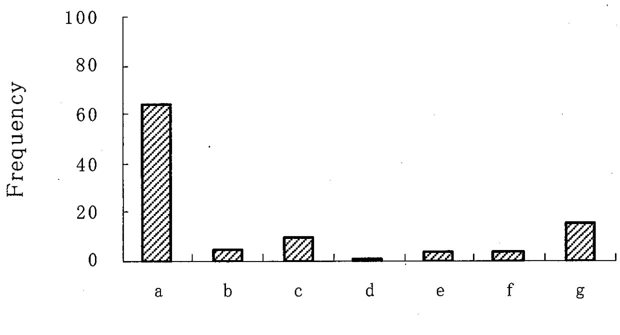

Fig. 3. Frequency of primary tree stems 7 years after strip clear-cutting.

states of primary trees, although there were some exceptions. The reason is, in general, that the forest has the highest frequency in the small DBH class, with gradual decreases in the number of stems towards the large classes (Fig. 1).[5,9)] In the present study, the smallest DBH group of 1-2 cm had 67 dead stems ("g"), which sharing 77.0% of the all dead stems, indicating that most dead stems were from small DBH groups. In fact, nearly one-fourth of stems were dead for DBH group of 1-2 cm. This group had the highest mortality frequency (Fig. 4b). The DBH group of 4-6cm had the highest frequency (90.0%) of type "a", whereas DBH group 12-20 cm hit the lowest frequency (40.0%) of type "a". DBH group 12-20 cm also had the highest frequency of type "b" (20.0%) and "c" (24.0%) among all DBH groups.

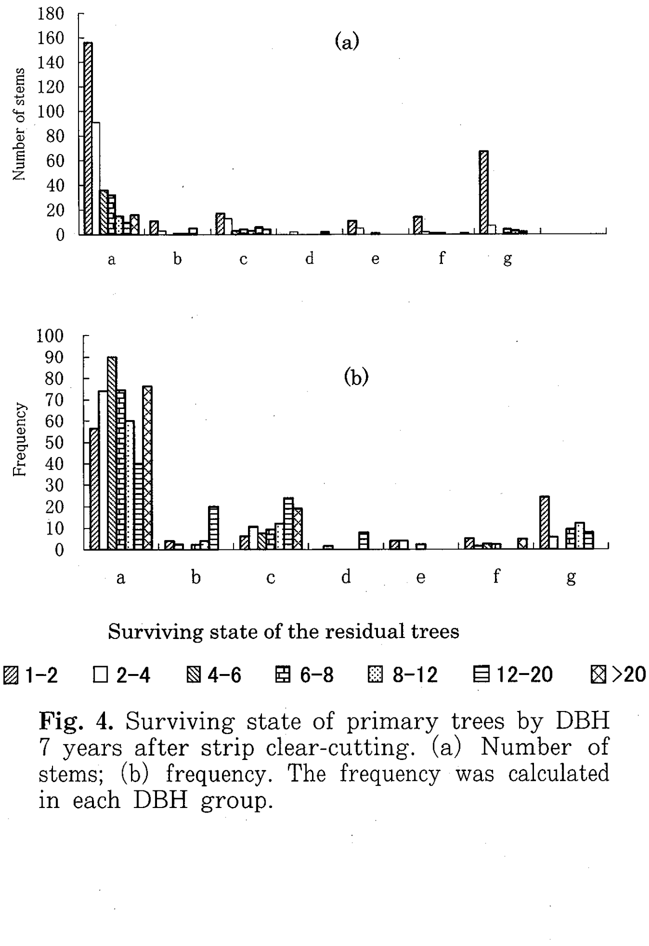

Fig. 4. Surviving state of primary trees by DBH 7 years after strip clear-cutting. (a) Number of stems; (b) frequency. The frequency was calculated in each DBH group.

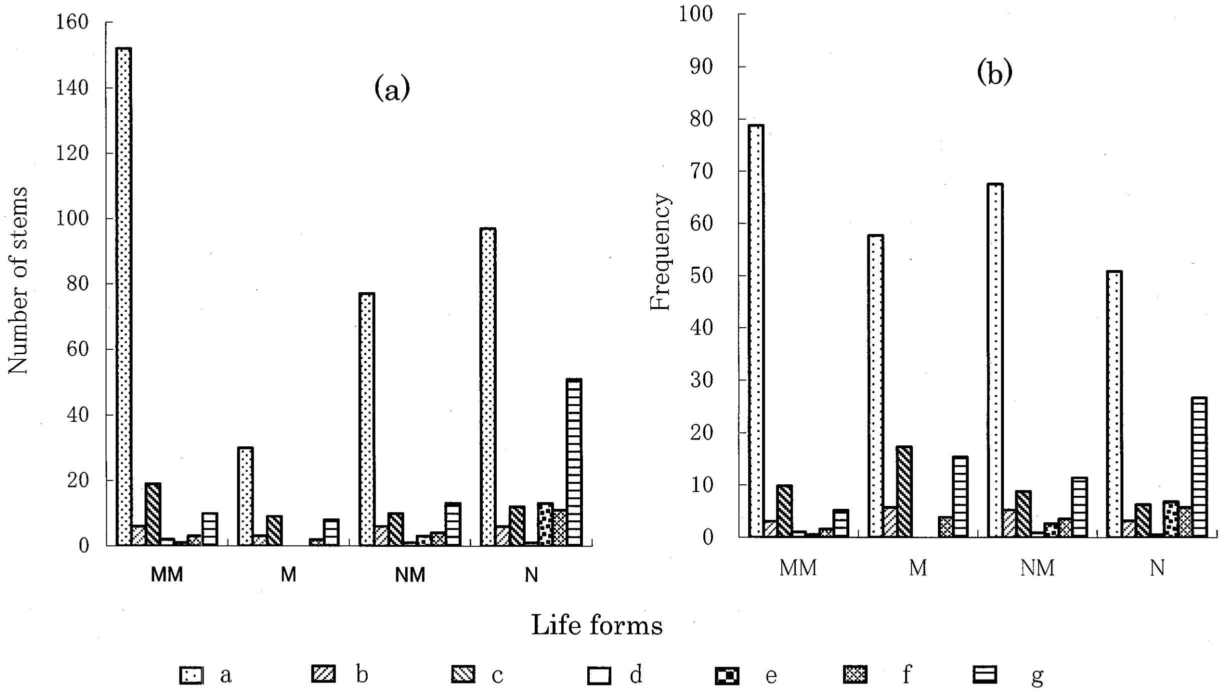

Fig. 5. Surviving state of residual trees by life forms 7 years after strip clear-cutting. (a) Number of stems; (b) frequency.

Table 2. Surviving state of main primary trees (stem number≧5) by species in the residual area 7 years after strip clear-cutting.

Species	a	%	b	%	c	%	d	%	e	%	f	%	g	%	Total
Ardisia quinquegona (Shishiakuchi)	71	47.3	5	3.3	6	4.0	1	0.7	12	8.0	11	7.3	44	29.3	150
Distylium racemosum (Isunoki)	106	81.5	3	2.3	11	8.5	1	0.8	1	0.8	2	1.5	6	4.6	130
Castanopsis sieboldii (Itajii)	23	71.9	1	3.1	6	18.8							2	6.3	32
Camellia lutchuensis (Himesazanka)	19	82.6	1	4.3	1	4.3							2	8.7	23
Randia canthioides (Shimamisaonoki)	15	65.2	1	4.3	1	4.3					1	4.3	5	21.7	23
Psychotna rubra (Bochoji)	14	77.8			2	11.1			1	5.6			1	5.6	18
Ilex ficoidea (Oshiibamochi)	13	76.5							1	5.9	1	5.9	2	11.8	17
Schefflera octophylla (Fukanoki)	11	73.3	1	6.7	2	13.3							1	6.7	15
Styrax japonicus (Egonoki)	6	50.0			3	25.0							3	25.0	12
Lasianthus fordii (Tashinoruniminoki)	2	22.2	1	11.1	1	11.1							5	55.6	9
Neolitsea sericea (Shirodamo)	3	33.3	1	11.1	2	22.2							3	33.3	9
Gardenia jasminoides f. *grandiflora* (Kuchinashi)	6	75.0	1	12.5	1	12.5									8
Cinnamomum sieboldii (Nicckei)	5	71.4					1	14.3					1	14.3	7
Dendropanax trifidus (Kakuremino)	6	85.7							1	14.3					7
Elaeocarpus japonicus (Kobanmochi)	3	50.0	2	33.3									1	16.7	6
Meliosma lepidota ssp. *squmulata* (Nanbanawabuki)	4	66.7			1	16.7							1	16.7	6
Ardisia sieboldii (Mokutachibana)	1	20.0			2	40.0					1	20.0	1	20.0	5
Callicarpa japonica var.*luxurians* (Omurasakishikibu)	4	80.0			1	20.0									5
Camellia japonica (Yabutsubaki)	5	100													5
Diospyros morrisiana (Tokiwagaki)	1	20.0	1	20.0	1	20.0					1	20.0	1	20.0	5
Other 31 species	38	65.5	3	5.2	9	15.5	1	1.7	1	1.7	2	3.4	4	6.9	58
Total	356	64.7	21	3.8	50	9.1	4	0.7	17	3.1	19	3.5	83	15.1	550

Species are listed by total number of stems.

2. Surviving states of primary trees by life forms

The stem number and frequency of primary trees for different surviving states by life forms are shown in Fig. 5. MM and N shared almost the same stem number (35.1%, 34.7%, respectively), followed by NM (20.7%) and M (9.5%). For surviving state of the primary trees, type "a" had the highest values (Fig. 5a), and hit the highest frequencies for all life forms (Fig. 5b). For life form N, type "g" had the highest stem number (51 stems) within life forms, and hit the highest frequency (26.7%) among four life forms, indicating that most dead stems were from life form N. The lowest mortality rate ("d"+ "g") was MM, hitting the value 6.2% only. The mortality rate by life forms in consequence was N>M>NM>MM, which was in agreement with the result of selective logging in the adjacent area.[8]

3. Surviving states of primary trees by trees species

The surviving states of the primary trees by species for trees whose stem numbers ≧ 5 were shown in Table 2. Of these 20 species, 4 species, including *Callicarpa japonica var. luxurians, Camellia japonica, Dendropanax trifidus, Gardenia jasminoides* f. *grandiflora,* were found to have no dead stems. Two species, namely *Camellia lutchuensis* and *Distylium racemosum,* had the type "a" higher or equal to 80.0%. The primary dominant species, C. sieboldii, hit a low mortality rate of 6.3% ("d"+"g") with most trees (71.9%) in regular state ("a"). The highest mortality rate ("d"+"g") species were *Lasianthus fordii, Neolitsea sericea* and *Ardisia quinquegona,* hitting the values of 55.6%, 33.3% and 30.0%, respectively. A. *quinquegona* had 51.7% of all dead stems due to its having the highest tree stems of all the species. In addition, 2 species, *Glochidion acuminatum* and *Myrsine sequinii,* which had stem numbers lower than 5, were found to have disappeared entirely.

Discussion

The impact of strip clear-cutting on the future structure, biological diversity and ecological function of forests is a topic of continuing debate.[10-11] Our results showed that most primary stems were in regular state (64.7%) seven years after strip clear-cutting, which was slightly higher than that at a nearby site laurel forest 8 years after selective cutting (58.2%).[8] The primary dominant species, C. *sieboldii,* had a low mortality rates of 6.3%, with most of stems in regular state (71.9%). The results of this study suggest that silvicultural systems using strip clear-cutting might be feasible for maintaining the natural laurel forest in Okinawa.

However, attention to the impact of wind-throw should be given. In Okinawa, typhoons frequently occur from July to October, bringing strong winds to the island. After strip clear-cutting, larger openings were suddenly created in the forest. The trees left at the edges of clear-cutting are exposed to stronger winds, making them more susceptible to wind-throw. In the present study, the DBH group 12-20 cm hit the type "b" and "c", 20% and 24%, respectively, and DBH >20 cm hit type "c" 19.0%, higher than those in small DBH groups (Fig. 4b). It seems that higher trees were more susceptible to wind-throw. In the field work, several big trees and branches were found broken down at treetop in the border between plots B and C damaged by the typhoon No.16, a powerful storm which occurred in 2002,. The breakdown of big trees or branches might affect both adjoining primary trees in the residual area and the regenerating trees in the clear-cut area.

In this study, *A. quinquegona* and *L. fordii,* which belong to life form N, were two of the highest mortality rate species, especially, *A. quinquegona* which shared 51.7% of all dead stems in the study plots. The N trees normally grow in the under-storey layer; the sudden changes by felling nearby may greatly effect their growth. For example, strong light, drying in the forest, and strong wind from the strip gap, may result in a higher mortality rate for N trees. Secondly, the direct damage from falling branches or stems of the primary MM or M trees, which was observed in the field work in type "b" and "c", may also result in the higher mortality rate of the N species. Furthermore, the pressure of population density by growth of the primary trees and invading trees may be considered as one of the reasons for the higher mortality rate of N trees.

In conclusion, 7 years after strip clear-cutting, the majority of stems (64.7%) in the residual area of the study plots remained in regular state without obvious damage, while 35.3% of them were in disturbance, namely, 15.8% of them were dead in fallen state or dead in standing state, 12.9 % of them were lived in standing state with breakdown at treetop with withered tops, and 6.6% of them were lived in fallen state. The results show the surviving states of primary trees differed by DBHs, life forms and tree species. The small DBH group 1-2 cm had the highest mortality rate, versus the big DBH group (>12 cm) which hit the highest rate of breakdown at treetop (over 19%). It seems that the taller the primary tree, the higher the damage rate. The higher damage rate of the big trees may be the effect of strong wind-throw through the gap of clear-cut strip.

It should be pointed out that, in this paper, we focused on the current states of the primary trees 7 years after strip clear-cutting. However, we did not give attention to the regenerating trees and invading ones. For evaluation of the strip clear-cutting system, not only the states of the primary trees but also the growths and states of the clear-cut trees, and their sprouts and seedlings should be considered. Further studies regarding the abovementioned strip clear-cutting system are needed.

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沖縄の照葉樹林における帯状伐採施業 7年後の保残区残存木の生育状態

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キーワード：帯状伐採施業，保残区残存木の生育状態，残存木の7タイプ類型，亜熱帯照葉樹林，天然更新

要　約

本論文は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．天然林施業試験林は沖縄島北部と西表島西部にあり，沖縄島北部では琉球大学農学部附属亜熱帯フィールド教育研究センター・与那フィールドに皆伐施業（1992年度），択伐施業（1993年度），帯状伐施業（1994年度）が設定された．帯状伐施業は天然林の面積3,600㎡で，斜面方向に10m幅の6帯状試験区A～Fが区画され，樹高1.2m以上の立木について樹種，樹高，胸高直径の毎木調査が行われた．保残区の直径分布はL字型を示し，材積64.7%のイタジイが優占した天然林であった．毎木調査の後，6帯状試験区は交互にA，C，Eの伐採区とB，D，Fの保残区に区分され，伐採区は全立木が地上20cm高で伐採された．各帯状試験区には10m×10mの方形調査区2個，計10個が設定された．本論文では帯状伐施業林設定7年後の保残区について，設定時の天然林残存木51種550個体の生育状態が調査，解析された．残存木の生育状態は7タイプに類型化され，胸高直径と生活形から考察された．生育状態は残存木の64.7%が健全で，35.3%が支障木であった．支障木35.3%の内訳は，枯死15.8%，頂端部の枯損12.9%，倒木6.6%であった．生存状態は胸高直径と生活形に関係していた．胸高直径1－2cmの小径群は枯死率がもっとも高く，胸高直径12cm以上の大径群は頂端部の枯損率が高くなった．生活形ではシシアクチのような低木種は枯死木のほとんどを占め，優占種であるイタジイは枯死率が6.3%で低く健全率が71.9%と高かった．シシアクチやタシロルリミノキのような林冠下に生育する低木種の枯死率が高いのは，伐採による生育環境の急激な変化，例えば強い光，乾燥，風の影響，また林冠木の折損枝の落下圧，さらに残存木の成長や新規発生木による密度圧などが考えられる．帯状伐施業は森林の循環利用にとってきわめて有効であるが，その施業法の確立のためには，保残区の残存木の生育，伐採区の二次遷移，根株の萌芽や実生，侵入種の更新，それらの相互作用など継続的な調査が必要である．