Ann. For. Sci. 65 (2008) 505
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DOI: 10.1051/forest:2008031

Available online at:
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Original article

Characteristics of a 20-year-old evergreen broad-leaved forest restocked by natural regeneration after clearcut-burning

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(Received 4 Dcember 2007; accepted 5 March 2008)

Abstract –
• To elucidate the application of natural regeneration to the restocking of evergreen broad-leaved forests in the subtropics, the characteristics of a 20-year-old evergreen broad-leaved forest restocked by natural regeneration after clearcut-burning were studied in Okinawa, Japan. Within a 0.87 ha clearcut area with four 10 m × 10 m sampling plots, two burned and two unburned ones, the tree composition, tree species diversity and vegetation changes were investigated.
• The results showed that the species diversity, basal area and density of woody stems ⩾ 1.0 m in height differed significantly among phanerophyte types, while they were not significantly different between the burned and unburned treatments. A vegetation census also revealed no obvious differences between the treatments.
• The primary dominant species, *Castanopsis sieboldii*, continued to dominate the secondary forest with a broad height distribution.
• The structural complexity and high tree species diversity of the regenerating forest after clearcut-burning provides no evidence of degeneration. We can predict that the regeneration forest may gradually develop into stands similar to pre-clearcut primary forest, and that natural regeneration may restore the high tree species diversity of the evergreen broad-leaved forests in Okinawa.

forest structure / species diversity / natural regeneration / subtropical evergreen broad-leaved forest / clearcut-burning

Résumé – Caractéristiques d'une forêt feuillue sempervirente âgée de 20 ans, reconstituée par régénération naturelle après coupe rase et feu.
• Pour élucider la pertinence de la régénération naturelle pour la reconstitution des forêts feuillues dans la zone subtropicale, les caractéristiques d'une forêt feuillue sempervirente, âgée de 20 ans, reconstituée par régénération naturelle après coupe rase et feu, ont été étudiées à Okinawa au Japon. Dans une coupe rase de 0,87 ha, 4 placeaux échantillons de 10 m × 10 m ont été établis : deux après coupe rase et feu et deux après coupe rase. On a étudié la composition des arbres, la structure de la forêt, la diversité spécifique des arbres et les changements de végétation.
• Les résultats montrent que la diversité spécifique, la surface terrière et la densité des troncs ligneux d'une hauteur supérieure ou égale à 1,0 m diffèrent significativement parmi les phanérophytes, tandis qu'il n'y a pas eu de différences significatives entre les traitements brûlés et les non brûlés. Le recensement de la végétation a aussi révélé qu'il n'y avait pas de différence évidente entre les traitements.
• La principale espèce dominante *Castanopsis sieboldii* a continué à dominer la forêt secondaire avec une large distribution des hauteurs.
• La complexité structurelle et la grande diversité des espèces d'arbre de la forêt régénérée après coupe rase et feu fournissent la preuve qu'il n'y a pas eu dégénérescence. Nous pouvons prédire que ces forêts peuvent se développer graduellement en peuplements similaires à la forêt primaire existant avant la coupe et que la régénération naturelle peut rétablir la grande diversité spécifique des arbres dans les forêts feuillues sempervirentes d'Okinawa.

structure de la forêt / diversité spécifique / régénération naturelle / forêt feuillue sempervirente subtropicale / coupe rase et feu

1. INTRODUCTION

In tandem with the acceleration of global environmental degradation in recent decades, natural regeneration of forests, given its environmental and natural conservation benefits, has become an important issue (Bermúdez et al., 2007; Harmer et al., 1997; Peterken, 1993; Zerbe, 2002). Although a number of studies on natural forest regeneration have been published, most of these have focused on deciduous or coniferous forests (Carlos et al., 1994; Francisco, 2003; Vincent et al., 2000), and not on evergreen broad-leaved forests (EBLFs) in the subtropics.

Clearcut-burning has traditionally been practiced as a cheap means of clearing forestlands for agriculture or forestry in many developing countries of Southeast Asia, Africa and South America (Coomes et al., 2000; Quevedo et al., 2007; Varma, 2003). In subtropical regions, particularly in southern China, clearcut-burning is practiced widely as a traditional measure for preparing forestland. In recent decades, large

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areas of natural EBLFs in China have been clearcut-burned for the establishment of fast-growth coniferous forests because of the higher economic benefits of the latter. Nevertheless, the technique has been widely criticized over the years as an important factor in reducing the global forested area, contributing to forest degeneration, and aggravating global warming. Following the rapid reduction in natural EBLFs in subtropical regions, there have been increasing calls for the protection and reconstruction of these forests. In recent years, the natural regeneration of forests has come to be regarded as an important forest regeneration measure designed to protect and restore the EBLFs in subtropical regions (Kyushu Forest Bureau, 2000; Wu and Shinzato, 2004). However, natural regeneration has rarely been used for the successful restocking of EBLFs in the subtropics. We currently know little about the natural regeneration of EBLFs following clearcut-burning in the subtropical regions. Therefore, there is a pressing need to investigate the secondary forest regeneration processes following the clearcut-burning of EBLFs in these regions.

EBLF dominated by *Castanopsis sieboldii* Hatusima is widely distributed on Iriomote Island, Okinawa, Japan, where a maritime subtropical climate prevails. Restoration of such forests through natural regeneration and protection of the unique natural island environment in Okinawa have become important study projects. Several studies have been conducted on natural sprouting regeneration forests in Okinawa (Shinzato et al., 1989; 2000; 2002; Wu and Shinzato, 2004; Wu et al., 2001; 2006). However, these studies are insufficient for gaining an understanding of overall characteristics such as the forest structure and tree species diversity arising from natural regeneration over the long term following severe anthropogenic disturbance. Bearing in mind the results of previous studies, the purpose of the present study was, firstly, to focus on tree composition, forest structure, tree species diversity and vegetation changes of a regenerated subtropical EBLF 20 years after clearcut-burning and, secondly, to gain a better understanding of the likely reasons for either the successful recovery of the forest or failure, resulting in degeneration of secondary regenerating forest, when using natural regeneration. In order to investigate these processes, study plots within an EBLF were initially subjected to either clearcut alone or clearcut followed by burning.

2. MATERIALS AND METHODS

2.1. Study site

The study was carried out in an undisturbed EBLF at the Iriomote Tropical Biosphere Research Center, University of the Ryukyus, Iriomote Island (24° 15–25′ N and 123° 40–55′ E), Okinawa, Japan. Iriomote Island (area, 289.27 km^2) is one of the principal islands of the southern Ryukyu Islands of Japan. Under the island's maritime subtropical climate, winters are frost-free, while summers bring frequent typhoons or tropical cyclones, and associated heavy rainfall and strong winds. The 30-year mean annual precipitation from 1971 to 2000 was over 2 300 mm. The mean annual temperature is 23.4 °C, with a monthly mean maximum of 28.3 °C in July, and a monthly mean minimum of 18.0 °C in January (Iriomote Climate Observation, 2002). The highest peak on the island is Mt. Komidake at 469 m above sea level (a. s. l.) Elevations at the study site range from 60 m to 100 m a. s. l. The study site is covered by well-developed EBLF forest. The bedrock is composed of sandstone, from which a yellow soil develops (Miyawaki, 1989). Soil samples were collected at each study plot, and further physical and chemical analyses revealed that there were no significant differences between the soils of burned and unburned plots prior to clearcutting (Yamamori et al., 1989).

2.2. Field methods

A 0.87 ha study area of undisturbed EBLF was selected on the mid-slope of a hillside in 1985. The slope is southwest facing with a gradient of 10° to 20°. The study area was divided into 4 adjacent sections of equal area. In the center of each section a 10 m × 10 m study plot was established and a census of all the trees with diameters at breast height (DBH) > 3 cm was undertaken. The parameters measured included DBH, height and species. Subplots (2 m × 2 m) for the vegetation census (< 1.0 m in height) were set up in the center of each plot; all trees and herbs were also recorded. Following the tree and vegetation census, clearcut was carried out in September over the entire study area. All trees were felled at the base, approximately 0.20 m above the soil surface. Two of the sections in the center were burned in November, while the remaining two sections were left unburned. The burning was carried out using the traditional local burning method, which arranges the felled trees in parallel rows 2 m apart. After a moderate level of fire lasting for 8 h on a sunny day, most of the felled trees, vegetation and organic matter on the forestland in the two burned sections were fully burned. However, most of the cut stumps (root collars) had retained their original shapes after the burning. The study site was then left undisturbed for 20 years before an August 2005 tree census. Tree species and stem height were noted for all trees exceeding 1.0 m in height; for those exceeding 1.3 m in height, DBH was also measured. A vegetation census was also carried out for both trees and herbs (< 1.0 m in height) occurring in the subplots.

2.3. Data analysis

The family importance value (IV_f) and species importance value (IV_s) were evaluated in plots according to the following formulae (Basnet, 1992; Mori et al., 1983):

$$IV_f = (RD + RBA + RFR)/3,$$
$$IV_s = (RD + RBA)/2,$$

where IV_f is the family importance value (%); IV_s is the species importance value (%); *RD* is the relative density, calculated as the number of stems of a given species in the plot(s), divided by the total number of stems of all species within the same plot(s) (%); *RBA* is the relative basal area, calculated in a similar manner to *RD*, but using the basal area rather than the number of stems (%); and *RFR* is the relative family richness, calculated by dividing the number of species of a given family within a plot by the total number of species of all families in the plot (%). For the purposes of this study, the dominant families or species were designated as those with an importance value higher than 5.0.

Two measurements were used to evaluate tree species diversity: species richness (S), which is the total number of species, and the Shannon-Wiener index (H'), which was calculated as follows (Magurran, 1988):

$$H' = -\sum p_i \log_2 p_i,$$

where p_i is the proportion of trees (% stems) in the ith species.

The woody trees (phanerophytes) recorded in the surveys were classified into one of four life-forms: megaphanerophytes (Mega; arbor), mesophanerophytes (Meso; mid-arbor), microphanerophytes (Micro; sub-arbor) and nanophanerophytes (Nano; shrub) (Hatusima, 1975). The differences in the number of tree species, stem density, and basal area between burned and unburned treatments were evaluated using a two-way analysis of variance, with one factor being the treatments (burned and unburned) and the other the four phanerophyte types.

3. RESULTS

3.1. Tree composition

A total of 34 tree species (> 3.0 cm DBH) was recorded in the primary forest before the clearcut; these species could be classified into 22 families and 27 genera (Tab. I). Of these species, 21 occurred on the clearcut-burn plots 20 years after the treatment, and 25 occurred on clearcut-only plots. The most common families in the burned treatment were Fagaceae ($IV_f = 26.0$) and Lauraceae (17.2). The same two families, Lauraceae (20.4) and Fagaceae (17.8), were also the most common in the unburned treatment. According to the species importance values, prior to the clearcut, 5 dominant species: *C. sieboldii* ($IV_s = 36.7$), *Persea thunbergii* (Sieb. et Zucc.) Kosterm. (23.4), *Tutcheria virgata* (Koidz.) Nakai (6.2), *Rhaphiolepis indica* (L.) Lindl. ex Ker (5.2) and *Ardisia sieboldii* Miq. (5.1) were present in plots that were destined for clearcut-burning, while 6 dominant species: *C. sieboldii* (24.7), *Cinnamomum doederleinii* Engl. (13.4), *P. thunbergii* (10.3), *Styrax japonicus* Sieb. et Zucc. (6.2), *Diplospora dubia* (Lindl.) Masam. (6.2) and *Elaeocarpus sylvestris* (Lour.) Poir. (5.1) were present in the plots destined only to be clearcut.

Twenty years after the clearcut, the four treatment plots contained a total of 1315 stems exceeding 1.0 m in height. These plants could be classified into 30 families, 49 genera and 69 species (Tab. I). The burned plots contained 61 tree species, which exceeded the number of species in the unburned plots (49 species). In the present study, it was observed that most species of the primary forest species remained after 20 years of regeneration; however, *Ilex ficoidea* Hemsl. and *Rhus succedanea* L. disappeared from the two unburned plots, while *Ternstroemia gymnanthera* (Wight et Arn.) Beddome disappeared from the two burned plots. Nevertheless, *I. ficoidea* and *R. succedanea* were present in the two burned plots. Twenty years after clearcut, the two burned plots combined contained 8 dominant families, whereas the two unburned plots contained only 5 dominant families. The most common family in both the burned ($IV_f = 24.9$) and unburned (24.3) plots was Fagaceae, followed by Rubiaceae, which was approximately half as common (11.4 and 12.4, respectively). In terms of IV_s, the dominant species of the two burned plots were *C. sieboldii* (36.5), *S. japonicus* (7.1) and *P. thunbergii* (5.9), whereas those of the two unburned plots were *C. sieboldii* (28.3), *Psychotria rubra* (Lour.) Poir. (7.1) and *Quercus miyagii* Koidz. (6.1). *C. sieboldii* was clearly the dominant species in the EBLF regeneration forest 20 years after clearcut in both burned and unburned treatments, although there were some changes in the other dominant species compared with those recorded in the primary forest before the clearcut.

3.2. Forest structure

Tree densities (height ≥ 1.0 m) were 34 600 stems ha^{-1} in the burned plots and 31 150 stems ha^{-1} in the unburned plots, whereas the corresponding basal areas were 43.0 and 45.6 m^2 ha^{-1} (Fig. 1). There were no significant differences in tree density ($F = 0.24$, $p > 0.63$) or basal area ($F = 0.52$, $p > 0.49$) between the burned and unburned plots; however, significant differences in stem densities ($F = 161.9$, $p < 0.0001$) and basal areas ($F = 7.52$, $p = 0.01$) occurred among the phanerophyte types.

The distributions of two treatments and dominant tree species are presented in Figures 2 and 3, respectively. Both of the treatments gave rise to the same size class distribution pattern, a typical reverse-J type (Fig. 2), which is characterized by species in the small height classes having the highest frequency, with a gradual decrease in the number of stems with increasing height class. For the dominant species, the following three distribution patterns of tree size class were found (Fig. 3). The abovementioned reverse-J-type distribution was observed for *P. rubra*, which exhibited the greatest density in the study plots. However, most individuals of this species ranged between only 1 and 2 m in height. *C. sieboldii* and *P. thunbergii*, which also have a broad height distribution peaking at 7–8 m and 5–6 m, respectively, exhibited a unimodal pattern. This pattern is characterized by species in the intermediate size classes having the highest frequency, with the smaller and larger classes having lower frequencies. The sporadic type indicates that the adjacent classes are badly represented: frequency rises again more and less sharply in intermediate classes, such as *Q. miyagii*, which was present only in the non-burned plots and had a broad distribution of heights, peaking at 8–9 m. *S. japonicus* also exhibited a unimodal pattern; however, the patterns appeared to differ between the two treatments. The abovementioned five dominant species contributed to a total basal area of 78.8 and 68.6%, respectively, in the burned plots and unburned plots, although they comprised only approximately 27% of the total stems by number in both treatments (Fig. 4). Notably, *C. sieboldii* contributed significantly to the total basal area (65.2 and 50.6%, respectively) in the burned and unburned plots, whereas *P. rubra* contributed only approximately 0.7% in both plots. Thus, *C. sieboldii* was represented by fewer but larger individuals, whereas *P. rubra* was represented by more numerous, smaller individuals.

Table I. Family importance value (IV_f) and species importance value (*IVs*) in plots before and 20 years after clearcut*.

Family or species	Regenerating forest in 2005						Primary forest in 1985					
	Burned plot			Unburned plot			Burned plot			Unburned plot		
	I	II	Total	I	II	Total	I	II	Total	I	II	Total
Fagaceae 2 species	**27.7**	**21.7**	**24.9**	**23.5**	**24.8**	**24.3**	**19.2**	**35.9**	**26.0**	**26.7**	**10.4**	**17.8**
Castanopsis sieboldii	**40.3**	**31.6**	**36.5**	**33.9**	**23.1**	**28.3**	**25.9**	**48.9**	**36.7**	**35.8**	**13.3**	**24.7**
Quercus miyagii					**12.1**	**6.1**						
Rubiaceae 8 species	**13.7**	**9.8**	**11.4**	**14.7**	**11.2**	**12.4**	3.0	**7.4**	**5.6**	3.7	**8.8**	**5.5**
Diplospora dubia	0.5	1.8	1.0	1.5	1.4	1.4	1.6	1.9	1.7	1.4	11.0	**6.2**
Psychotria rubra	4.9	2.7	4.0	**8.1**	**6.3**	**7.1**						
Lauraceae 3 species	4.7	**6.8**	**5.9**	**6.0**	3.3	4.2	**23.4**	**12.4**	**17.2**	**25.8**	**17.1**	**20.4**
Cinnamomum doederleinii		0.2	0.1	0.1	1.1	0.6				**24.8**	1.9	**13.4**
Persea thunbergii	**5.8**	**6.0**	**5.9**	3.4	1.5	2.4	**32.1**	**13.6**	**23.4**	**5.5**	**15.3**	**10.3**
Myrsinaceae 4 species	**6.9**	4.0	**5.7**	**5.3**	**6.1**	**5.4**	4.7	**7.5**	**5.0**		2.5	1.8
Ardisia quinquegona	**5.4**	2.4	4.1	0.8	2.9	2.0						
Ardisia sieboldii	1.4	0.2	0.9	1.1	2.3	1.8	4.1	**6.3**	**5.1**			
Theaceae 5 species	4.1	**6.3**	**5.4**	2.9	4.6	4.0	3.6	**12.4**	**8.2**			
Camellia japonica		**7.3**	3.1	3.0	4.2	3.6						
Tutcheria virgata	0.9		0.5		0.7	0.4		**13.6**	**6.2**			
Euphorbiaceae 6 species	4.2	**7.2**	**5.3**	4.0	**5.4**	**5.0**	**6.5**	4.6	**5.2**			
Aquifoliaceae 6 species	**6.1**	4.3	**5.3**	2.7	3.2	3.0	**6.2**	4.8	**6.7**	**7.7**	**15.8**	**10.7**
Ilex goshiensis	0.1		0.1	0.6	0.2	0.4					**6.4**	3.2
Ilex liukiuensis	0.5	1.3	0.8		0.7	0.4		2.2	1.0		**7.6**	**3.8**
Styraceceae 1 species	**7.4**	2.9	**5.3**	4.7	2.5	3.4	2.0	**6.3**	2.9	**11.1**		**5.5**
Styrax japonicus	**9.9**	3.3	**7.1**	**5.6**	2.8	4.1		2.7	1.2	**12.5**		**6.2**
Moraceae 4 species	4.9	3.9	4.5	1.8	0.9	1.2	3.8		2.6			
Elaeocarpaceae 2 species	3.8	3.8	3.8	**8.0**	4.6	**5.9**				**10.1**	**7.9**	**7.4**
Elaeocarpus sylvestris	2.9	4.7	3.7	**5.3**	4.1	4.7				4.3	**5.9**	**5.1**
Rosaceae 1 species	3.2	2.4	2.7	3.3	3.5	3.3	**8.3**		**5.0**	**5.8**	2.4	3.3
Rhaphiolepis indica	3.6	2.6	3.2	3.6	4.1	4.0	**9.5**		**5.2**	4.6	1.4	3.0
Symplocaceae 3 species	2.7	2.5	2.3		3.8	1.6	3.3		2.3	**6.7**	4.7	4.1
Rutaceae 3 species	1.9	2.1	1.9	1.2	2.2	1.6						
Verbenaceae 3 species	1.4	2.2	1.8	2.4	2.1	2.4						
Ebenaceae 2 species	1.4	2.1	1.8	2.7	2.4	2.3	4.4		2.9		**5.3**	3.8
Myrtaceae 1 species	1.3	3.0	1.8	2.7	3.2	2.9	3.1		2.2		2.4	1.8
Sapotaceae 1 species	1.6	1.9	1.5	3.8	4.2	3.9					3.6	2.4
Planchonella obovata	1.2	1.8	1.5	4.4	**5.3**	4.9					3.1	1.5
Araliaceae 1 species		2.2	1.2	3.6	0.8	2.1	4.0	**6.5**	4.1	4.0		2.0
Leguminosae 1 species		2.2	1.2									
Oleaceae 1 species	0.9	2.0	1.2	1.9	1.3	1.4	3.1		2.2			
Daphniphyllaceae 1 species	0.9	1.8	1.1		1.2	0.9	3.4		2.4		2.8	2.0
Staphyleaceae 1 species	1.3		0.9									
Myricaceae 1 species		1.3	0.8									
Celastraceae 2 species		0.9	0.7	1.5	3.2	2.6						
Flacourtiaceae 1 species		1.0	0.7									
Ulmaceae 1 species		1.0	0.7									
Sabiaceae 1 species		0.8	0.6		1.2	1.0						
Magnoliaceae 2 species				1.1	2.0	1.8					**6.7**	3.9
Michelia compressa				0.2	1.0	0.6					**7.8**	3.8
Hamamelidaceae 1 species					1.5	1.1					4.1	2.6
Guttiferae 1 species				1.2	0.8	0.9				3.9		2.0
Anacardiaceae 1 species											2.9	2.0

* The dominant families and species of each plots, with an importance value 5.0. are marked in bold figures.

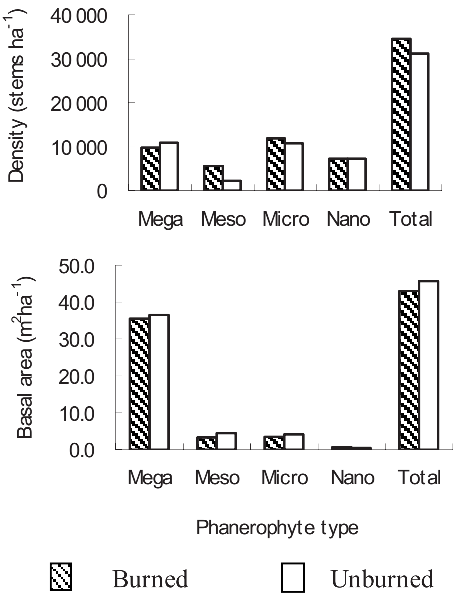

Figure 1. Density and basal area of phanerophyte-type plants in a 20-year-old clearcut-burning regeneration in the subtropical evergreen broad-leaved forests on Iriomote Island, Okinawa.

3.3. Tree species diversity

Species diversity is an important ecological-structural characteristic of a community, contributing to its stability (Dewoody et al., 2003; Tilman and Downing, 1994). Burned plots had species richness (S) and Shannon-Wiener diversity (H') values of 61 and 5.04, respectively, while for unburned plots these values were 49 and 4.81, respectively (Fig. 5). However, differences in neither of these indices were significant: S (F = 0.27, $p > 0.27$) and H' (F = 0.05, $p > 0.82$). In contrast to the lack of significant differences in species diversity between burned and unburned plots across all species, differences within phanerophyte types were highly significant for both S (F = 17.30, $p < 0.001$) and H' (F = 7.12, $p = 0.01$).

3.4. Vegetation changes

Twenty years after the treatment, the regenerating forests in 2005 averaged 107 and 66 stems (for both tree and herb species < 1.0 m in height), respectively, in the burned and unburned subplots. These numbers are considerably lower than those recorded in the primary forests in 1985 (Tab. II). The regenerating forests also had considerably lower values for S, although only slightly lower values for H', in both treatments compared with the primary forest. For the dominant species in the regenerating forest, one tree species, *Rhaphiolepis indica* (L.) Lindl. ex Ker, was absent in the two treatments; while 4 herb species, such as *Lindsaea heterophylla* Dryand. and *Oplismenus compositus* var. patens, were absent in both treatments. *Lophatherum gracile* Brongn. was absent from burned plots but present in unburned plots with one stem

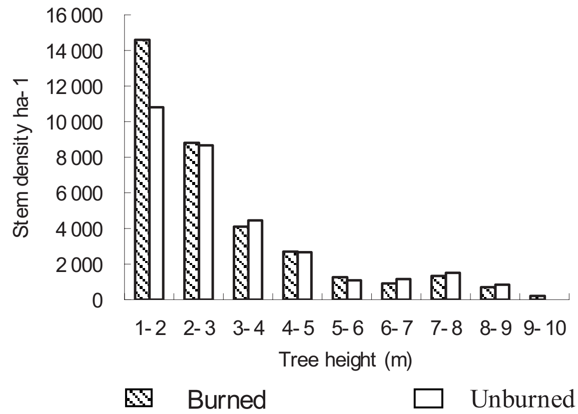

Figure 2. Frequency distribution by height class for a 20-year-old clearcut-burning regeneration in the subtropical evergreen broad-leaved forest on Iriomote Island, Okinawa.

only. Tree species such as *P. rubra*, *P. thunbergii* and *Diospyros maritima* Bl.clearly decreased in abundance in both treatments. Based on the aforementioned observations, it appears that after 20 years of natural regeneration there are no obvious differences between the vegetation established on burned and unburned plots.

4. DISCUSSION

On Iriomote Island, the *Adinandra yaeyamensis–Castanopsietum sieboldii* Miyawaki community generally develops where tertiary sandstone and shale occur (Miyawaki, 1989). In general, the community is dominated by *C. sieboldii* (mega-phanerophyte), which comprises the highest layer with a mean tree height of 8~12 m, accompanied by other mega- or meso-phanerophyte species. In the present study, *C. sieboldii* exhibited the highest importance values, ranging from 23.1 to 40.3, in both the burned and unburned plots. These values were approximately 4 times those for *P. rubra*, which had the second highest importance values, ranging from 2.7 to 8.1. This indicates that *C. sieboldii* continues to rank as the dominant species in the clearcut regeneration forest. This species exhibits a broad distribution of heights, peaking at 7–8 m in the highest layer, with similar frequency distributions in both the burned and unburned plots. This finding suggests that the layer structure in the regenerating stand was similar to that in the natural stand prior to cutting. Furthermore, from a long-term perspective, the mega-phanerophytes included 16 tree species (Fig. 5), each with approximately 10 000 stems ha^{-1} in both the burned and unburned plots, and these species comprised the majority of the total basal area in the plots (Fig. 1), This observation suggests that the mega-phanerophyte species of the regeneration forest might continue to dominate the forest in the future. While the above-mentioned mega-phanerophytes were abundantly represented in the regeneration forest, a large variety of meso-, micro- and nano-phanerophyte species were also present. For example, *P. rubra,* a nano-phanerophyte species, was present in the

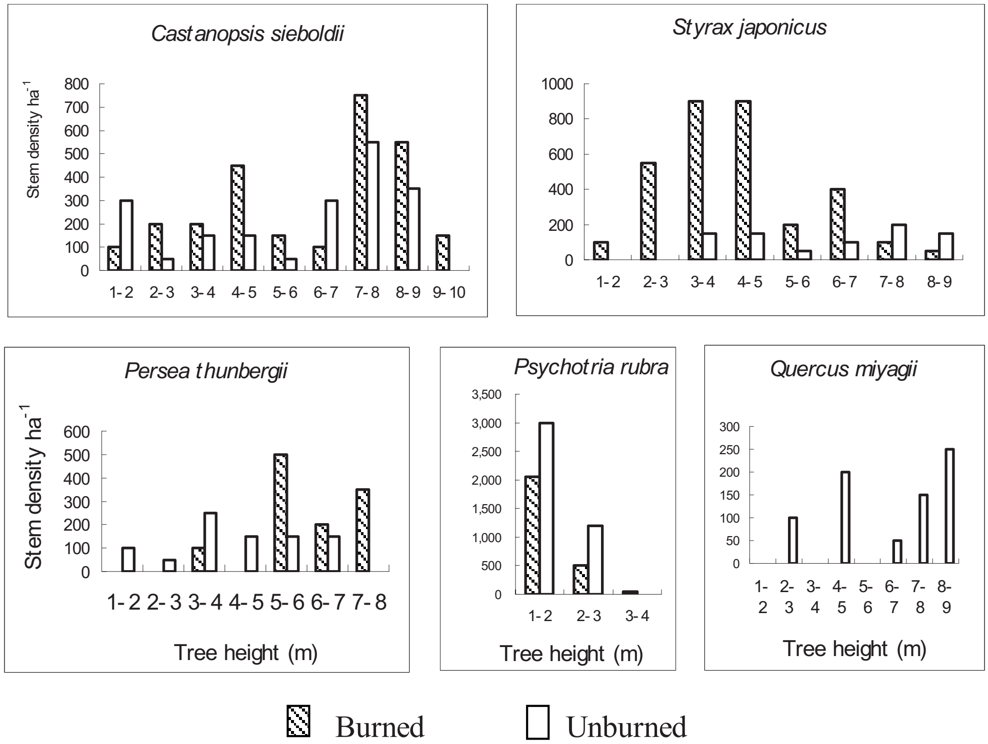

Figure 3. Frequency distribution by height class for five dominant species in clearcut-burning regeneration in the subtropical evergreen broad-leaved forest on Iriomote Island, Okinawa.

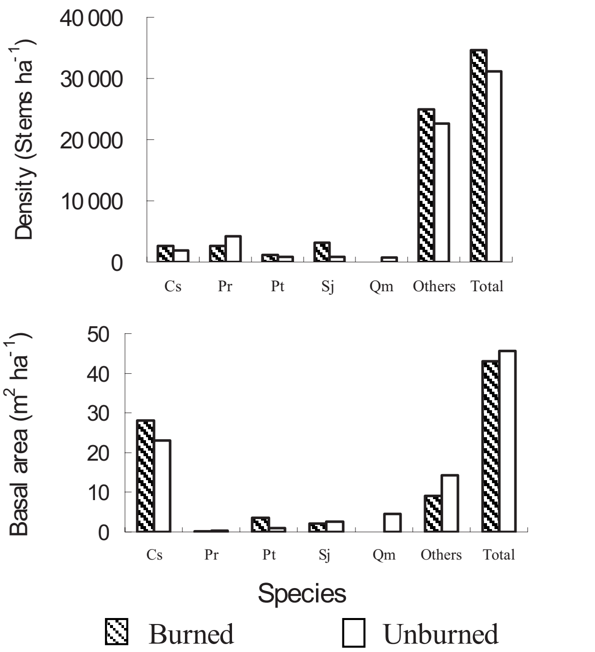

Figure 4. Density and basal area of five dominant species, and other species, in the subtropical evergreen broad-leaved forest on Iriomote Island, Okinawa. Abbreviations: Cs, *Castanopsis sieboldii*; Pr, *Psychotria rubra*; Pt, *Persea thunbergii*; Qm, *Quercus miyagii*; Sj, *Styrax japonicus*.

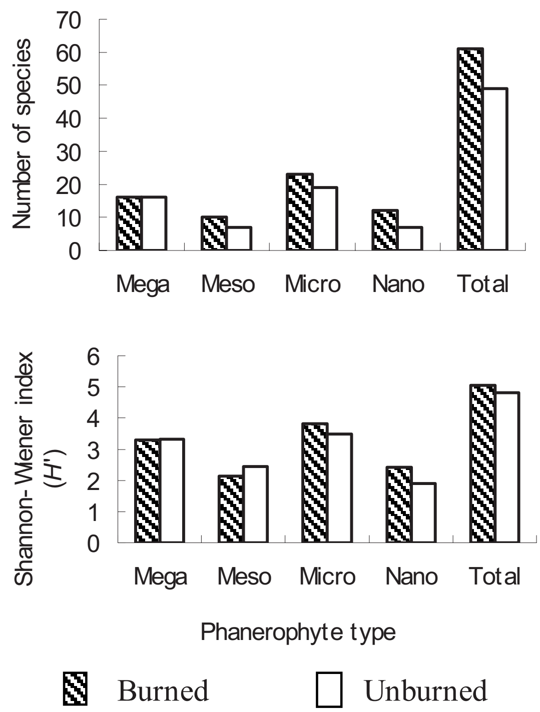

Figure 5. Tree species diversity by phanerophyte-type in clearcut-burning regeneration in the subtropical evergreen broad-leaved forest on Iriomote Island, Okinawa.

Table II. Density, species richness, Shannon-Wiener index and dominant species of vegetation (<1.0 m in height) with number of stems / relative density (%) in the subplots (2 m × 2 m in size)*.

Treatment	Primary forest in 1985						Regenerating forest in 2005					
	Burned plot			Unburned plot			Burned plot			Unburned plot		
	I	II	Total	I	II	Total	I	II	Total	I	II	Total
Density	1 238	1 074	1 156	625	847	736	151	62	213	61	71	132
Species richness	67	64	75	56	60	70	37	23	43	24	18	32
Shannon-Wiener index	4.8	4.6	4.9	4.7	5.2	5.3	4.2	4.0	4.5	4.2	3.4	4.4
Dominant tree species												
Persea thunbergii	174/14.1	46/4.3	220/9.5	3/0.5	51/6.0	54/3.7	1/0.7	1/1.6	2/0.9	1/1.6		1/0.8
Psychotria rubra	151/12.2	181/16.9	332/14.4	43/6.9	54/6.4	97/6.6	3/2.0	2/3.2	5/2.3	1/1.6	2/2.8	3/2.3
Diospyros maritima	36/2.9	42/3.9	78/3.4	20/3.2	52/6.4	72/4.9	1/0.7	2/3.2	3/1.4	2/3.3		2/1.5
Styrax japonicus				1/0.2		1/0.1				1/1.6	21/29.6	22/16.7
Rhaphiolepis indica	51/4.1	61/5.7	112/4.8	31/5.0	46/5.4	77/5.2						
Ardisia quinquegona	11/0.9	8/0.7	19/0.8	2/0.3	7/0.8	9/0.6	7/4.6	4/6.5	11/5.2	3/4.9		3/2.3
Dominant herb species												
Lindsaea heterophylla				43/6.9		43/2.9						
Oplismenus compositus	113/9.1	114/10.6	227/9.8	1/0.2	18/2.1	18/1.2						
Adiantum flabellulatum	12/1.0	40/3.7	52/2.2	100/16.0		100/6.8						
Lophatherum gracile	100/8.1	10/0.9	110/4.8	25/4.0	9/1.1	34/2.3				1/1.6		1/0.8
Smilax bracteata	32/2.6	5/0.5	37/1.6	3/0.5	43/5.1	46/3.1						
Lindsaea orbiculata	80/6.5	106/9.9	186/8.0	68/10.9	14/1.7	82/5.6	4/2.6		4/1.9		1/1.4	1/0.8
Heterosmilax japonica.	19/1.5	23/2.1	42/1.8	11/1.8	38/4.5	49/3.3	2/1.3	3/4.8	5/2.3	1/1.6	14/19.7	15/11.4
Ophiopogon jaburan										4/6.6	5/7.0	9/6.8
Dioscorea pseudo-japonica							10/6.6	2/3.2	12/5.6	5/8.2		5/3.8
Flagellaria indica	4/0.3	6/0.6	10/0.4	1/0.2	34/4.0	35/2.4	4/2.6	15/24.2	19/8.9	12/19.7		12/9.1

* Dominant species dominated at least in 1985 or 2005 in burned or unburned treatments.

lowest layer with the greatest density and peaking at 1~2 m in height. This finding suggested that the stand structure of the regenerating forest is likely to be complex in both burned and unburned treatments due to the development of multiple canopy layers.

The stem density of a secondary forest arising by natural regeneration is different from that by plantation. In a plantation forest, the density is determined at the time of planting, whereas in a natural regeneration forest, stem density is a mixture of the sprouting capacity of the cut trees and the availability (arrangement, production and dispersal) and germination capacity of their seeds (Shinzato et al., 1989). In the early stage of natural regeneration, a huge number of tree stems may arise from stumps or seeds. It should be noted, however, that the patches studied in this investigation were very small, which probably had a significant affect on seed availability. Larger patches could behave quite differently in this respect. At a site in the northern part of Okinawa Island, Wu and Shinzato reported a density (height > 1.0 m) of 101 513 stems ha^{-1} 5 years after the clearcut of an EBLF (Wu and Shinzato, 2004). In the present study, the stem densities in the burned and unburned plots on Iriomote Island were 34 600 and 31 150 stem ha^{-1}, respectively, but had been 50 650 and 49 250 stems ha^{-1}, respectively, in the 13th year after clear cutting (Shinzato et al., 2002), and 38 900 and 37 650 stems ha^{-1}, respectively, in the 18th year (Wu et al., 2006). The subsequent decline in abundance after the peaks observed after 13 years can be attributed to the severe competition between individuals for space and nutrients, together with an increase in basal area, resulting in the death of weak competitors. However, compared with the density of a similar natural forest stand (23 663 stems ha^{-1}) in the northern part of Okinawa Island (Shinzato et al., 2000), the densities of the 20-year regeneration plots remained high, suggesting that the densities would continue to decrease over the years. Concomitant with the decrease in stem densities, the basal area increased over time. Twenty years after the clearcut, the total basal areas of the trees exceeding 1.3 m in height on the burned and unburned plots were 43.0 and 45.6 m^2 ha^{-1}, respectively, whereas they had been 33.8 and 36.4 m^2 ha^{-1}, respectively, in the 13th year after the clearcut and 39.2 and 37.5 m^2 ha^{-1}, respectively, in the 18th year. This result indicates that the basal area would probably continue to increase. Thus, there is a trend toward fewer, larger stems over time.

In this study, due to the lack of permanent numbered labels on the bases of trees prior to cutting, it was subsequently difficult to determine the sources of the stems (sprouting- or seedling-origin). However, the distinct sprouting-origin stems, which were easily recognized during the fieldwork, accounted for 35.4 and 37.9% of the total stems in the burned and unburned treatments, respectively, and contributed to 74.5 and 58.7%, respectively, of the total basal areas in the two treatments. This finding indicates that the regenerating forest was dominated by sprouting stems rather than seedling stems. The frequency distribution (Fig. 3) also revealed that the primary dominant species, *C. sieboldii* and *P. thunbergii*, were present abundantly in the high layer on the burned plots, and the tree census revealed most of these were stems of sprouting origin. This observation suggests that clearcut-burning did not cause an extensive death of the cut stumps. The survival and growth of the sprouting stems of the primary dominant species may be responsible for the small difference in forest structure between the burned and unburned treatments.

On the other hand, as a result of clearcut followed by burning, the previously forested lands were suddenly exposed, allowing a large number of pioneer species, such as *Mallotus japonicus* Muell.-Arg., *Mallotus paniculatus* Muell.-Arg. and *G. acuminatum*, to colonize the former forestland and contribute to its subsequent composition. Such species were present at 13 years after cutting (Shinzato et al., 2002); in particular, *M. japonicus*, a deciduous broad-leaved species, with 98 and 46 stems in burned and unburned plots, respectively, represented 13.7 and 5.9%, respectively, of the total basal areas in the burned and unburned plots. This indicates that there had been more pioneer species in the clearcut-burn treatment than in the clearcut-only treatment. However, over the subsequent 7 years, along with the decrease in stem densities and rise in basal area of primary species, the abundance of the abovementioned 3 pioneer species declined precipitously to only 2 stems left in the burned treatment and nothing in the unburned treatment. The sharp decrease in pioneer species also suggests that the regenerating forests in the two treatments were undergoing a progressive succession.

Several studies on tree species diversity of natural EBLFs in the Ryukyu Islands have been published over the last two decades. Ono et al. (1997) reported that tree species diversity was lower in the Ryukyu Islands than on the Japanese mainland. Conversely, others have demonstrated that the tree species diversity of the forests in Okinawa was higher than that on the Japanese mainland (Xu et al., 2001), and that the species diversity increased with increasing forest age (Ito, 1997). In the present study, the vegetation established on clearcut-burned plots had slightly higher tree species diversity values than the vegetation on clearcut-only plots. The values of S and H' for the EBLF regeneration were 61 and 5.04, respectively, in the burned plots, and 49 and 4.81, respectively, in the unburned. These values were higher than those for an EBLF (14 and 3.04, respectively) on the Japanese mainland (Omura et al., 1969), but lower than those (120 and 6.05, respectively) of a tropical rainforest in the Hainan Province of China (Peng and Zhou, 1989). These observations indicate that the secondary regeneration forest established on Iriomote Island following a 20-year recovery had high tree species diversity, and that the traditional forest burning did not result in a decrease in tree species diversity compared with the clearcut-only treatment. It should be pointed out, however, that it is difficult to compare our data with that of others due to the different ages of stands, sampling areas, and so on. Nevertheless, the present study is likely to reflect the high species diversity of the secondary regenerating EBLF after clearcut-burning by natural regeneration on Iriomote Island.

However, the vegetation census (< 1.0 m in height) conducted for the subplots revealed that the regenerating forest had a slightly lower species diversity than that of the primary forest, and that both treatments resulted in considerably lower stem densities and species richness than in the primary forest (Tab. II). The main reason for these differences may be the change in niche after clearcut or clearcut-burning, which resulted in the massive death of the seedlings of shade-intolerant species, such as *Adiantum flabellulatum* L., *O. compositus* and *Smilax bracteata* Presl., which disappeared from both plot types in the secondary forests following the treatments. The decreases in stem density, S, and H', and the concomitant disappearance of shade-intolerant species, suggests that the vegetation recovery may be slower than tree revegetation after the treatments.

5. CONCLUSIONS

The abundance of mega-phanerophytes accompanied by a large variety of other phanerophytes in both burned and unburned treatments suggests that the structure of the regeneration forest was complex due to the development of multiple canopy layers. Following 20 years of natural recovery, although there were small differences between the burned and unburned treatments, in general, clearcut-burning of a subtropical EBLF on Iriomote Island appears to have had little effect on the forest structure or tree species diversity compared with the unburned clearcut treatment. The clearcut-burning regenerating forest exhibited no signs of degeneration, but rather a progressive succession. Based on the above results we can predict that the regeneration forest may gradually recover and develop into a stand similar to that prevailing before the clearcut-burning. The present results suggest that natural regeneration may restore the high tree species diversity of the EBLFs on the Ryukyu Islands. This research should also be helpful for forecasting the vegetation recovery and regeneration of village forests in the subtropics, where forests are often disturbed by farming, particularly in China where clearcut-burning is still practiced widely for the preparation of forestland. It should be pointed out, however, that since Iriomote Island is a small island and the mountain slopes are short and steep, the preparation of forestland by burning usually takes place on a small scale. In addition, since the present results were based on only a small number of duplicate plots, further studies with an increased number of duplicate plots are necessary in order to examine the influences of clearcut-burning on EBLF forest regeneration.

Acknowledgements: We thank the staff of the Iriomote Tropical Biosphere Research Center, University of the Ryukyus, for their help in the fieldwork. Thanks are also extended to the students of the University of the Ryukyus for their assistance in the fieldwork. Financial support was partly provided by a Grant-in-Aid for JSPS Fellows and by the National Natural Science Foundation of China (30640004).

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* The titles are tentative translation from Japanese titles by the authors of this paper.