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Measuring mortality of different species stump with DBH in a naturally regenerated clearcut subtropical forest

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Abstract: Within the framework of a series of forest recovery researches of a subtropical evergreen broadleaved forest, this study was carried out to measure mortality rates of tree stumps changed by species diameter at breast height (DBH) based on the surveys of 62 woody species and 1,893 tree stems taller than 1.2 m in four 20 m × 10 m plots were recorded in 1993. At an August 1998 tree census five years after clearcut, all sprouting stems higher than 1.0 m were identified, and the statuses of all the residual stumps were checked. The investigation showed that 382 stumps were dead without any living sprouts whereas 1,511 stumps were survived with living sprouts. The further studies showed that the mortality rates of stumps did not vary with DBH of the stand, but vary with the species DBH remarkably. The mortality rates by stump DBH within species for these whose total stump numbers ≧10 stems in the study plots were divided into four patterns: (a)With the increasing DBH, the mortality rates increased. (b) Inversely, with the increasing DBH in a certain extent, the mortality rates decreased. (c) With an increasing DBH, the mortality rates decreased at first and then increased to some extent. (d) The mortality rates were independent of DBH. The above results suggested that different species might have different mortality patterns, and that different tree species might have different rational DBH ranges for sprout natural regeneration. This knowledge could be much useful for forest recovery forecasting when the severe forest disturbances occurred in subtropical regions.

Key words: subtropical evergreen broad-leaved forest; mortality rates of stumps; clearcutting system; natural regeneration

Introduction

The concept of natural regeneration is not new among foresters in the world. It appears in most silvicultural texts and practical handbooks [1,2]. But it is a process that has rarely been used for successful restocking of evergreen broadleaved forest in subtropical regions. Most foresters have little practical experience of natural regeneration of broad-leaved forest in comparison to planting. However, with the development of the world, environmental damages have become worst. Much attention has been paid to natural regeneration because of environmental and conservation benefits that natural regeneration can bring.

Clearcut has traditionally been practiced as a cheap means of clearing forests for agriculture or forestry in many developing countries of Southeast Asia, Africa and South America [3,4]. In subtropical regions, especially in China, clearcut is also practiced widely as a traditional measure for preparation of forestland. In recent decades, large areas of natural evergreen broad-leaved forests in China were clearcut for the construction of fast-growth coniferous forests because of the higher economic benefits of the latter. However, few attentions were paid to natural regeneration after clearcut of the broad-leaved forests in subtropical areas. Therefore, there is a pressing need to understand the secondary forest regeneration processes for the evergreen broadleaved forest after clearcut in subtropical regions. In this paper, we discussed the measuring mortality rate of cut stump for an evergreen broadleaved forest after clearcut on northern Okinawa Island in Japan, and hope that this study could also give guidance for the natural regeneration of evergreen broadleaved forest in south China where clearcut is still widely used for the preparing of forestland.

In the past two decades, several reports related to natural regeneration of broad-leaved forest in Okinawa, Japan, have been done. Hirata [5,6] studied the survival rate of stumps and the mean sprout number per stump approximately four to five months after selection cutting. Asato [7] reported the stand structure and growth of target species 3 years after cutting. Shinzato et al studied the mortality changes by species, life-form spectra, and the diameter at breast height (DBH) 5 years post clearcut [8]. Wu et al studied the stand structure 5 years post clearcut for a natural subtropical evergreen broad-leaved forest in northern Okinawa [9]. But the effects on mortality rate associated with species DBH remain unclear. This paper covers our work of the mortality rates of stumps by DBH for different tree species. This knowledge could prove to be very useful with forest recovery and regeneration forecasting after severe forest disturbances in subtropics.

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Material and Methods

1. Material

The study site was selected in a natural forest within the University Forest that is associated with university of the Ryukyus. The forest is located in the northern part of Okinawa Island, Japan (26° 45′ 30″ N and 128° 05′ E). The altitude ranges from 300m to 330m above sea level. The mean annual precipitation measured at Yona University Forest was 2,650 mm, the mean annual temperature was 21.6° C, the mean monthly maximum temperature was highest in August (32.1℃), and mean monthly minimum temperature was lowest in February (10.8℃) during the past two decades.

The study area was covered with an evergreen broad-leaved forests dominated by Castanopsis sieboldii,which shares 68.1 % of stand volumes. The compositionof main tree species about mean DBH, mean tree height,density and standing volume before cutting, are shown in Table 1. The parent bedrock is sandy shale, and the soil is classified as yellow soil [10]. In addition, the thickness of soil horizon is more than 80 cm, and the thickness of soil humus horizon is between 4~12 cm.

Table 1. Outline of main tree species in an evergreen broadleaved forest at study plots before clearcut in Okinawa.

Species	Mean DBH (cm)	Mean tree height (m)	Tree density (trees ha^{-1})	Volume	
				m^3 ha^{-1}	%
Castanopsis sieboldii	15.1	7.2	1,263	94.7	68.1
Schima wallichii ssp.liukiuensis	12.3	8.0	300	16.3	11.8
Elaeocarpus sylvestris	7.3	6.3	188	3.0	2.2
Schefflera octophylla	7.1	5.9	338	4.9	3.5
Camellia lutchuensis	3.8	4.0	675	2.1	1.5
Myrsine sequinii	2.2	3.1	1,263	1.1	0.8
Distylium racemosum	2.1	3.1	2,350	1.9	1.3
Ardisia quinquegona	1.0	2.2	6,363	0.9	0.6
others	2.6	3.3	11,125	14.1	10.1
Total			23,863	139.0	100.0

2. Methods

Four plots (20 m × 10 m, in size) were established in a natural forest in 1992. Each plot was divided into two subplots (10 m × 10 m, in size). At the first inventory in 1992, 1,893 trees taller than 1.2 m in the study plots were recorded including the species name, tree height, and DBH. The measurements were tagged on the stem of each tree at the base. All trees were felled at the base about 20 cm height above the ground in February 1993. Field investigation was performed in 1998 between May and July. Each subplot was sub-divided into 25 quadrates (2 m × 2 m each) for convenience of investigation. The species of all the living trees taller than 1.0 m were recorded, and for those exceeding 1.3m in height, DBH was also measured. Especially, the stumps which were cut in 1993 were rechecked including both of number of sprout shoots and decay state of the stumps.

Results and discussion

Sprout regeneration takes very important role on natural regeneration of forest following clearcut or severe disturbances. By the preexisting root systems to take up the nutrients from soil, the sprout stems grow fast and take prevailing position in composition of species compared to seedling tree species. Sprout regeneration is considered to be an important measure for forest recovery at a global scale. In the previous study, Shinzato *et al* studied the mortality rate of DBH of all tree species and decay of stumps, and found that the mortality of stump did not change with the stand DBH [8].

The question remains about whether the mortality of stump changes with varying DBH within species of trees five years post clearcut. There are no related reports found so far associated with natural evergreen broad-leaved forest and this question. In the present study, the results showed that the mortality rates of stumps varied with species significantly (Table 2). Two species, mainly *Eurya osimensis* var. *kanehirae* and *Turpinia ternate,* had no living stumps. Adversely 16 species, for example, *Callicarpa japonica* var. *luxurians, Ilex liukiuensis,* had no dead stumps, and 44 species, for instance, *C. sieboldii, Schima wallichii* ssp. *liukiuensis,* had not only living stumps but also dead stumps. In general, 382 stumps were dead, while 1,511 stumps were survived with living sprout.

There were 33 tree species whose total stump numbers were ≧10 stems in the study plots, showed that the mortality rate

Table 2. Mortality rates of stumps changed by specie DBH at the sprouting regenerating forest following 5 years clearcut in Okinawa.

Species	DBH≤1			1<DBH≤2			2<DBH≤5			5<DBH≤10			10<DBH≤20			DBH>20			Total		
	dead	living	%	dead	living	%	dead	living	%	dead	living	%	dead	living	%	dead	living	%	dead	living	%
Callicarpa japonica var. luxurians	0	4	0				0	1	0										0	5	0
Vaccinium wrightii				0	1	0				0	2	0							0	3	0
Symplocos lucida	0	1	0	0	1	0	0	1	0										0	3	0
Cinnamomum doederleinii	0	1	0																0	1	0
Neolitsea sericea				0	1	0	0	4	0	0	2	0	0	2	0				0	9	0
Diplospora dubia				0	2	0	0	3	0										0	5	0
Diospyros morrisiana	0	4	0	0	3	0	0	2	0	0	1	0	0	1	0				0	11	0
Nageia nagi							0	1	0										0	1	0
Cinnamomum sieboldii	0	4	0	0	1	0							0	1	0				0	6	0
Rhus succedanea										0	1	0	0	1	0				0	2	0
Eurya japonica				0	1	0	0	2	0										0	3	0
Symplocos glauca							0	1	0										0	1	0
Symplocos confusa				0	1	0													0	1	0
Ilex integra				0	4	0				0	2	0							0	6	0
Meliosma simplicifolia ssp. rigida	0	1	0	0	1	0	0	5	0	0	1	0							0	8	0
Ilex liukiuensis	0	3	0	0	2	0	0	1	0										0	6	0
Ilex ficoidea	0	17	0	1	11	8.3	1	19	5.0										2	47	4.1
Persea thunbergii	2	21	8.7	0	4	0	0	9	0	0	7	0	0	1	0				2	42	4.5
Elaeocarpus sylvestris	0	2	0.0	0	1	0	0	7	0	0	2	0	0	1	0	1	1	50.0	1	14	6.7
Cinnamomum pseudo-pedunculatum	1	11	8.3	1	10	9.1	0	4	0	0	1	0							2	26	7.1
Elaeocarpus japonicus	3	9	25.0	0	11	0	2	16	11.1	0	18	0	0	2	0				5	56	8.2
Syzygium buxifolium	0	7	0	2	7	22	1	15	6.3	0	3	0	0	1	0				3	33	8.3
Antidesma japonicum	5	31	13.9	0	14	0	0	1	0										5	46	9.8
Rhaphiolepis indica	0	2	0	0	3	0	1	4	20.0										1	9	10.0
Osmanthus marginatus	1	1	50.0	0	3	0	0	3	0	0	1	0							1	8	11.1
Camellia lutchuensis	1	9	10.0	0	10	0	2	20	9.1	0	8	0	3	1	75				6	48	11.1
Randia canthioides	7	37	15.9	1	19	5	2	18	10.0										10	74	11.9
Schima wallichii ssp. liukiuensis				0	1	0	1	3	25.0	0	6	0	2	7	22	0	4	0	3	21	12.5
Myrica rubra							0	3	0	1	1	50.0	0	2	0				1	6	14.3
Psychotria rubra	6	30	16.7	3	22	12	1	7	12.5										10	59	14.5
Distylium racemosum	19	52	26.8	3	57	5	5	36	12.2	0	14	0	0	1	0	1	0	100	28	160	14.9
Viburnum japonicum	1	6	14.3	1	7	13	1	4	20.0										3	17	15.0
Castanopsis sieboldii	11	10	52.4	0	4	0	0	3	0	0	6	0	2	17	11	1	31	3.1	14	71	16.5
Ardisia quinquegona	52	273	16.0	33	135	20	1	15	6.3										86	423	16.9
Schefflera octophylla	1	0	100	0	2	0	1	8	11.1	0	9	0	3	3	50				5	22	18.5
Ficus erecta	1	2	33.3	0	1	0	0	1	0										1	4	20.0
Ilex goshiensis	1	3	25.0	0	0		1	3	25.0	0	1	0	0	1	0				2	8	20.0
Neolitsea aciculata	7	12	36.8	0	6	0	0	7	0	0	2	0							7	27	20.6
Thicheria virgata	2	10	16.7	3	2	60	2	12	14.3	1	6	14.3							8	30	21.1
Wendlandia formosana	0	1	0	0	0		0	2	0	1	0	100							1	3	25.0
Ardisia sieboldii	2	2	50.0	0	5	0	2	3	40.0	1	2	33.3							5	12	29.4
Persea japonica	3	4	42.9	0	1	0	1	2	33.3	0	1	0	0	1	0				4	9	30.8
Gardenia jasminoides f. grandiflora	2	10	16.7	0	3	0	2	5	28.6	4	2	66.7	1	0	100				9	20	31.0
Camellia japonica	9	7	56.3	1	11	8.3	3	8	27.3	5	4	55.6							18	30	37.5
Symplocos anomala				4	2	67	1	2	33.3	0	2	0	0	2	0				5	8	38.5
Meliosma lepidota ssp. squmulata	1	2	33.3	1	1	50	2	4	33.3	2	1	66.7							6	8	42.9
Daphniphyllum glaucescens ssp. teijsmannii	1	0	100	1	1	50	2	3	40.0	0	1	0	1	1	50				5	6	45.5
Myrsine sequinii	14	21	40.0	12	15	44	13	16	44.8	7	2	77.8	1	0	100				47	54	46.5
Rhododendron tashiroi	1	0	100	1	2	33	2	5	28.6	2	1	66.7	1	0	100				7	8	46.7
Illicium anisatum	1	0	100	0	1	0													1	1	50.0
Litsea acuminata	1	0	100							0	1	0							1	1	50.0
Ilex maximowicziana var. mutchagara				0	1	0	3	3	50.0	2	1	66.7							5	5	50.0
Microtropis japonica	0	1	0				1	1	50.0	1	0	100							2	2	50.0
Adinandra ryukyuensis							2	0		2	2	50.0	0	0		0	1	0	4	3	57.1
Styrax japonicus				1	0	100	2	0		0	0		0	2	0				3	2	60.0
Tarenna gracilipes	10	6	62.5	4	3	57	1	1	50.0										15	10	60.0
Lasianthus fordii	4	2	66.7																4	2	66.7
Helicia cochinchinensis	1	1	50.0				1	0											2	1	66.7
Skimmia japonica var. lutchuensis	2	0	100	5	2	71													7	2	77.8
Dendropanax trifidus				0	1	0	9	1	90.0	9	0	100	1	0	100				19	2	90.5
Eurya osimensis var. kanehirae	1	0	100	1	0	100	1	0	100	1	0	100	1	0	100				5	0	100
Turpinia ternata							1	0											1	0	100

of stumps changed within species DBHs. In the study, four patterns of mortality rates within species DBH were found (Table 3) : (a) Along with the increasing DBH, the mortality rates increased. Seven species were present in this type, for example *Dendropanax trifidus* and *Myrsine sequinii* achieved mortality rates 100% when DBH was higher than 5.0 and 10.0 km, respectively (Fig. 1a). (b) Inversely, with the increasing DBH in a certain extent, the mortality rates decreased. There were 9 species in this pattern, for instance, *Neolitsea aciculata* and *C. sieboldii*, most dead stumps occurred at the DBH class that was equal to or less than 1.0 cm (Fig. 1b). (c) Along with an increasing DBH, the mortality rates decreased at first

Table 3. Mortality patterns changed by species for species whose total stump number was ≧10 stems in the study plots.

Pattern	Species	Number of species
a	*Camellia lutchuensis, Dendropanax trifidus, Elaeocarpus sylvestris, Gardenia jasminoides f. grandiflora, Ilex maximowicziana var. mutchagara, Myrsine sequinii, Rhaphiolepis indica*	7
b	*Antidesma japonicum, Ardisia quinquegona, Castanopsis sieboldii, Cinnamomum pseudo-pedunculatum, Elaeocarpus japonicus, Neolitsea aciculata, Persea thunbergii, Symplocos anomala, Syzygium buxifolium*	9
c	*Camellia japonica, Distylium racemosum, Rhododendron tashiroi, Schefflera octophylla*	4
d	*Ardisia sieboldii, Daphniphyllum glaucescens ssp. teijsmannii, Diospyros morrisiana, Ilex ficoidea, Ilex goshiensis, Meliosma lepidota ssp. squmulata, Persea japonica, Psychotria rubra, Randia canthioides, Schima wallichii ssp. liukiuensis, Tarenna gracilipes, Thtcheria virgata, Vibumum japonicum*	13

and then increased to some extent. Four species were present in this pattern. For example, *Rhododendron tashiroi* and *C. japonica* were belonged to this pattern (Fig. 1c). (d) The mortality rates were independent of DBH. Thirteen tree species were in this pattern, for example, *S. wallichii ssp. liukiuensis* and *Ilex goshiensis* (Fig. 1d).

Huang *et al.* reported that the survival rate of stumps of *Acacia auriculiformis* decreased with the increasing DBH of stump [10]. In the present study, the result showed that the mortality varied with DBH for different species remarkably.

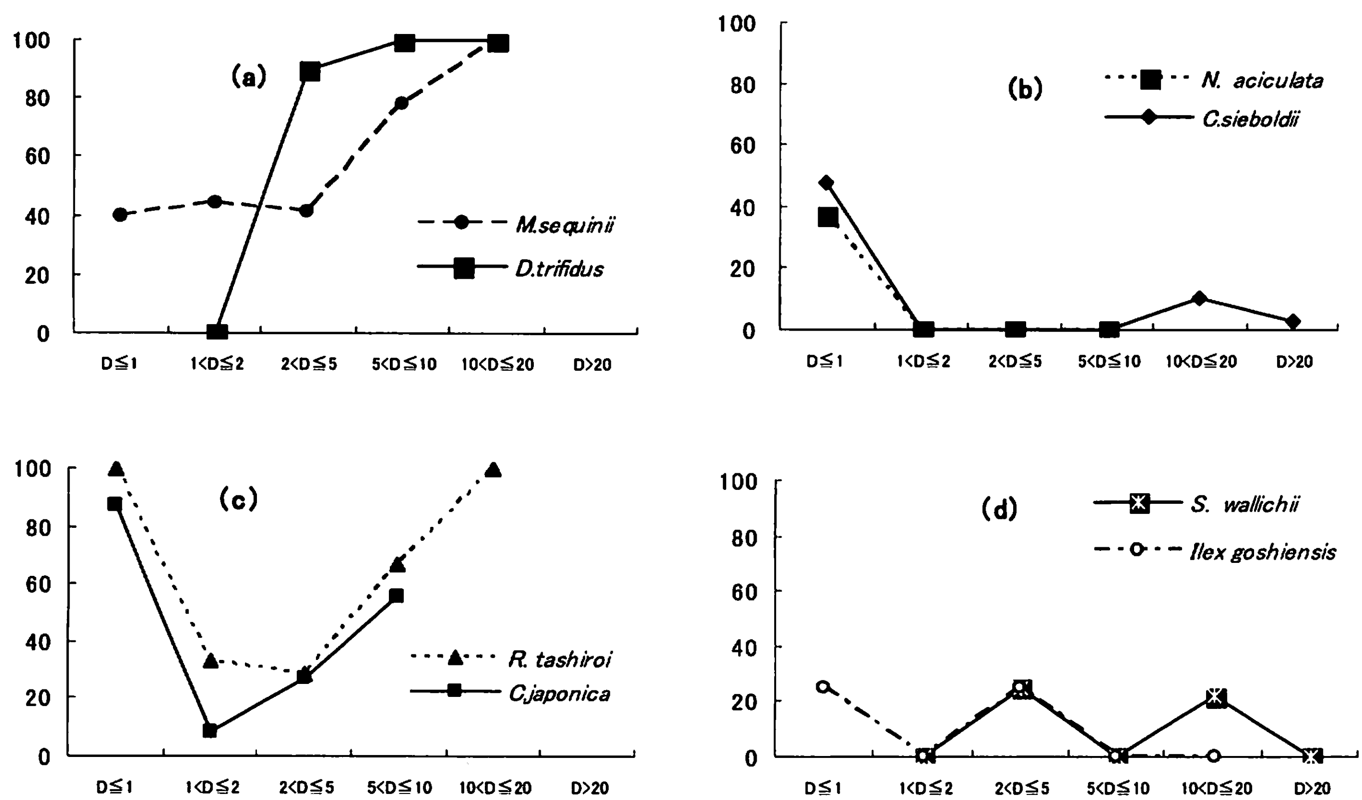

Fig. 1. Distribution of mortality patterns by species DBH for the species whose total stump numbers ≧10 stems in the study plots in Okinawa. (a) With the increasing DBH, the mortality rates increased. (b) Inversely, with the increasing DBH in a certain extent, the mortality rates decreased. (c) With an increasing DBH, the mortality rates decreased at first and then increased to some extent. (d) The mortality rates were independent of DBH.

It suggested that different species might have different pattern of mortality. Almost all living-stumps like D.trifidus, which belongs to type one, are small diameter stumps. These small diameter stumps whose sprout canopy is located in the lower layer probably result in death when intensive cutting methods are used followed by natural forest restoration because of their weak space competitive ability.

Different species might have not only different pattern of mortality but also different rational DBH ranges for sprout regeneration. In the present study, nineteen of the twenty-one stumps were found dead of D. *trifidus*, however, the field investigation showed that the two living stumps grew vigorously. Further study showed that one living stump located in DBH class of 1.0~2.0 cm, another in 2.0~5.0 cm (Table 2). Mainly, when DBH was over than 5.0 cm, all 10 stumps were dead without any living one. This strongly suggests that the appropriate DBH for sprout regeneration to D. *trifidus* was less than 5.0 cm. Huang *et al*. also found a similar result for *A. auriculiformis* plantation. The rational DBH range for sprout regeneration was between 4.0 and 8.0 cm [11].

In conclusion, following 5 years of natural regeneration of a post clearcut subtropical evergreen broad-leaved forest on a northern Okinawa Island in Japan has been shown that mortality rates of the residual stumps did not vary with general DBH of all species, but vary with DBH of individual species remarkably. The results indicated that different species might have different rational DBH ranges for sprout regeneration. With the first pattern of mortality, more attention should be paid to it because of heavy mortality for big sized stumps.

It should be pointed out that the present results were undertaken on a small scale, and that the paper only discussed the 33 tree species whose total stump numbers were ≧10 stems in the study plots, other 29 tree species were not treated here due to small number of stumps based on present data. Therefore, further study is needed to confirm the mortality patterns for main tree species on a large scale in Okinawa. However, the article compares results with the available resources and discusses future prospects for forest recovery and regeneration forecasting using natural regeneration after severe forest disturbances in subtropical regions.

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

亜熱帯広葉樹林皆伐後樹種の胸高直径による根株の枯死率

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摘要：本研究は、亜熱帯常緑広葉樹林の森林回復に関する研究の一環として、1993年に沖縄島北部の琉球大学農学部与那フィールドの林地に設置された試験地を対象に、皆伐施業5年後の1998年に根株の生育と毎木調査を実施した。今回は主として、根株の生育、とくに枯死状態について報告する。皆伐施業試験地では、設定された天然林当時の樹高1.2m以上の立木62樹種、1,893個体のうち、382個体の根株が枯死し、1,511個体の根株に萌芽が認められた。根株の枯死率は、全個体で胸高直径間には明確な差がなく、樹種別の胸高直径間に差がみられた。根株個体数が10個体以上の33樹種別および胸高直径別の根株枯死率は4型に類別された：(a)胸高直径の増加にともなって枯死率も増加した（カクレミノ、タイミンタチバナなど7種）；(b)胸高直径の増加にともない一定の直径範囲で枯死率が減少した（イヌガシ、イタジイなど9種）；(c)胸高直径の増加にともない枯死率は初め減少し、その後増加した（サクラツツジ、ヤブツバキなど4種）；(d)枯死率は胸高直径と関係がなかった（イジュ、ツゲモチなど13種）。萌芽力に対して、根株枯死率の類型別に異なることが示唆された。

キーワード：亜熱帯常緑広葉樹林，根株枯死率，皆伐施業，天然更新