Effects upon medium and understory tree individuals after
the dieback of red pine (Pinus densiflora) in Saijo Basin,
Hiroshima Prefecture, Japan

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In this study, the effects upon medium and small-sized tree individuals after the dieback of red pine were investigated in Saijo Basin, Hiroshima, in terms of forest structure, tree-ring chronologies, energy balance, vessel parameters of stem cross sections, and the biomass of dead pines. It was found from forest structure that the canopy layer has been greatly reduced due to the withering of red pines, and the highest class has shifted down to medium-sized trees such as Cryptomeria japonica, Quercus serrata, Acanthopanax sciadophylloides, and Tsuga heterophylla. Also, it was found from tree-ring chronologies that such medium-sized individuals were increasing their thickening growth. This coincides with the fact that downward short-wave radiation can now reach the middle layers so that they are guaranteed the radiation necessary for photosynthesis, and the percentage of vessel area has risen to support the increasing growth. Such changes began in the second half of the 1970s. However, understory individuals such as Eurya japonica, Lycia ovalifolius, and Ilex crenata have been left lightly stressed. Also, the dead biomass of red pines was estimated to be 2.204 to 10,870 t ha⁻¹. The dieback accelerated the growth of medium-sized trees but it did not encourage the growth of small-sized trees near the forest floor. Consequently, the two layers, which had remained together in the forest before the dieback, have increased the distances between them.

Key words: broadleaf tree, dead biomass, energy balance, red pine (Pinus densiflora), tree-ring, vessel area

INTRODUCTION

In inland basins of the Chugoku District, residences are set close to hills because there are
so few flat lands. The Saijo Basin is a typical example. The everyday life of farmers has been closely related to the hills, which are called Satoyama, with a height of 500-600 m above sea level (Yamaba and Nakagoshi, 1996). Water for irrigation is supplied from ponds gushed from slopes (Fukuoka et al., 1995). There are several types of land ownerships such as private forests which are owned usually in a strip along a slope, locally-controlled forests for communities (Zaisan-ku), which are distributed on both slopes and flat lands, forests owned by temples and shrines, and prefectural or national forests which aim at water resource management. Except for forests which are protected for matsutake mushroom cultivation and for public forests in which construction is designed to prevent landslides and to invite visitors for recreation activities, scenic beauty, or historic interests, the forests are almost all left unmanaged. What is common is that people have stopped cutting juvenile trees and using fallen branches and leaves since the 1960s (Kamada and Nakagoshi, 1991), and red pines (Pinus densiflora), which were dominant species in this area, have begun withering since the 1970s (Shiratsuki et al., 1999).

Most red pines, standing decayed like white pencils, have not been removed in private forests because of financial difficulties. Mushroom production has largely decreased due to the decline of red pines (Yamaba and Nakagoshi, 1999). Nowadays, many forests are used only for visiting graves. In public forests, line felling, in which all trees are cut down and piled up on slopes at an interval of about 5 m along contours, and tree plantings of super pines, which are genetically tolerant to wilt disease, have been proceeding since the 1990s. However, little else has changed except for the change of species to be planted from cedar/cypress to super pine. From these circumstances, broadleaf tree species, which used to live under red pines, are greatly accelerating their growth although they are still juvenile. In contrast, corrosion of dead pines has reached their roots, and in June and September 1999 debris flows swept away forest slopes at 46 sites in the basin.

The disappearance of canopy layers brings an improvement in lighting conditions to understory tree individuals. In tropical forests with a canopy height over 30 m, most individuals grow slowly before they reach the canopy. The individuals which enjoy sufficient sunlight are less than 5% of all trees, and other trees have to persevere despite the lack of light (Brokaw, 1987, Uhl et al., 1988). It has been reported that diurnal solar radiation on forest floors is about one-twentieth that above the trees (Whitmore et al., 1993, Ackerly and Bazzaz, 1995, Marques Filho and Dallarosa, 2000). The growth of understory individuals is suppressed, and some of them change growth-strategies so as to adapt themselves to the dark environment as shade-tolerant species (Tsuchiya et al., 2002). If a tree-fall gap is formed, buried seeds germinate all together and seedlings also start extension growth, but the area is limited (Platt and Strong, 1989, Vazquez-Yanes and Orozco-Segovia, 1994). On the other hand, canopy individuals also cannot extend their heights unlimitedly because, to have further growth, they have to absorb soil water with increasingly-stronger cohesion (Fitter and Hay, 1981, Schulze et al., 1985, Lovisolo and Schubert, 1998). To overcome gravitational potential, hydraulic conductivity must be increased (Calkin et al., 1986, February et al., 1995). These mechanisms concerning stratification, competition, lighting stress, and extension are all common at any place. Therefore, this study focuses on broadleaf trees which have remained near forest floors, and changes after the dieback of red pines. In particular, biotic and microclimatic factors such as forest structure, thickening growth, lighting environment, vessel parameter, and dead biomass of red pines are investigated.
METHODS

Fieldwork was carried out from 2000 to 2001 in a tree-felling site at the southern slope of Mt. Ryuu (360 m a.s.l.) and at a western slope of Mt. Matsuga where debris flows occurred at the height of 300-400 m. In the former (Site A: Figure 1), seedlings of cypress have been planted after line felling as a public work of Hiroshima Prefecture to prevent mountains of water resources. During July to August 2000, just before line felling, a forest inventory was conducted in a quadrat with an area of 2,500 m², and 151 stems were obtained after the felling. The inventory was intended for a tree with a diameter over 3 cm at ground level. The number of individuals and stems in each species, tree heights, and stem diameters were investigated. Concerning red pines, first, they were judged to be alive or dead. Then, stems with a thickness of 10 cm were cut using a saw. In the beginning of June and the middle of August 2001, energy balance was measured using a net radiometer (Eiko, MR40) and a photon flux meter (Koitco, IKS25) in the middle layer (7 m from the ground surface) and forest floor (1 m high) of a non-felling forest which neighbors the quadrat. Data was collected on cloudy (June) and sunny days (August). Because there was only one set of equipment, it was impossible to measure simultaneously in both of the layers. Upward and downward short-wave and long-wave radiation data, as well as photosynthetically active radiation data, were collected into data loggers (Eiko, MR75D) at intervals of 10 minute during 48 hours. The sensor arm of the net radiometer was fixed to a tripod at the ground, and in the middle layer it was mounted to a rectangular piece of wood and was tied to a stem ramifying into two branches at a height of 7 m. The second site (Site B) is in a private forest. Photographs of the northern and western slopes of Mt. Matsuga (0.71 km²) were taken from a hot-air balloon in December 2000, and the number of standing decayed red pines was counted. The area was divided into two blocks to avoid a site where debris flows occurred in 1999. Because stem broken or fallen individuals could not be seen from the balloon, a belt-transect was set up in the under, middle, and upslope to measure both stem diameters at heights of 10 cm (D₄₃) and the tree heights of living, stem broken, and fallen red pines, which totaled 300 in number.

Fig. 1. Study areas in Saijo Basin. Contour interval is 100 m. Bold line is 500 m above sea level.
Stems obtained were used in measuring tree-ring widths and vessel areas. First, stems were sliced with a chip saw (Makita, 2711) to a thickness of 1 mm. Then, the cross sections were glued to a rectangular piece of wood using epoxy resin (Konishi, Bond E Set), and were polished using a grinder (Nichika, BP35) on which sand paper was attached (#100-#2,000). Tree-ring widths up to 1999, a year before sampling, were read along the major and minor axes by combining a measure scope (Nikon, MM22) with an x-y counter (Nikon, SC112) which has an accuracy of 0.001 mm. When a stem was too large to slice at one time, it was cut into a few blocks. Images of vessels were taken using a CCD camera (Tokyo Electric Industry, CS5510) mounted to a measure scope, and were analyzed using image analysis software (Mitsui, Mac Scope 2.5). That is, the locations of vessels were carefully marked using a manually-operated pen on a monitor, including several parameters such as the area of each vessel, circumferences, the numbers of vessels in the range of interest (ROI), and the percentage of the area. One large tree-ring was separated into several parts because the ROI was 1.92 mm². Four species were used in image analysis (Quercus serrata, Ilex crenata, Ilex rotunda, and Eurya japonica), and a tree-ring formed in 1999, a year before sampling, and a 1969 tree-ring, 30 years before sampling, which were selected along the major axis of stem cross section, were used for the analysis.

RESULTS

1. Forest structure

In the 2,500 m² quadrat at Site A, there were 899 trees with a diameter over 3 cm at the ground surface (Table 1). With respect to conifers, there were 168 red pines and 105 cedars (Cryptomeria japonica). All the other trees were broadleaf, totalling 13 species and 626 individuals.

<table>
<thead>
<tr>
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<th>Botanical family</th>
<th>Num of indivs</th>
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<td>Kuronawatari</td>
<td>AQUIFOLIACEAE</td>
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<tr>
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<td>Himeyashabushi</td>
<td>BETULACEAE</td>
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<tr>
<td>11</td>
<td>Rhododendron reticulatum</td>
<td>Kobanomatatsutsutsuki</td>
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<td>Yamahaxe</td>
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<td>10</td>
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<td>Aohada</td>
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<tr>
<td>15</td>
<td>Spruce japonica</td>
<td>Egonoki</td>
<td>STYRACACEAE</td>
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</tbody>
</table>

899/2500 m²

Some red pines had a diameter of about 40 cm, but most of them were already broken or fallen. There were 18 living individuals, 47 standing decayed, and 103 stem broken or fallen. The mortality was almost 90%. In the tree height class shown in Figure 2 (a), P. densiflora (No.2) has the highest frequencies in the classes of 5-10 m and 10-15 m, but they consist of small-sized living and standing decayed individuals. If stem broken and fallen individuals maintain the tree heights that they had while alive, the distribution moves to upper class. Under red pines,
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medium-sized species such as cedar (No.4), _L. rotunda_ (No.5), _Acanthopanax sciadophyloides_ (No.7), and _Q. serrata_ (No.8) were most frequent in the 5-10 m class, and in the 0-5 m class another species cluster was found including _E. japonica_ (No.1), _L. ovalifolia_ (No.3), and _Symlocos coreana_ (No.6) as shown in Fig. 2 (b) and (c). Further, _I. crenata_ and _Rhododendron reticulatum_ were also found near the ground, although the number of individuals was small. Some of these understory individuals sprouted from original stems, and they possessed multiple stems (percentage of individuals with multiple stems: 34.2%).

2. Tree-ring chronology

Stem cores were not available from dead pines due to the decay of sapwood, regardless of whether they were standing decayed, stem broken, or fallen individuals. From living pines, however, the tree age was estimated to be 31.20 ± 6.77. Likewise, it was 57.41 ± 25.57 for cedar, and 29.99 ± 11.73 for broadleaf species. There were three cedars which exceeded 90 years in age. Most samples of broadleaf species had an age of about 30, and the maximum one was 67. Figure 3 shows cumulative ring width chronologies of four representative patterns. Figure 3 (a) is an example of small-sized red pines which have been suppressed in terms of lighting. Their radiiuses are only about 3 cm even though they are 30 year-old individuals. Judging from their heights (average: 5.9 m), they have been in the shade of broadleaf trees, accelerating their growth after the decline of large-sized pines. Cedars in Fig. 3 (b) have a long age, but growth was slow until the first half of the 1970s. Then, the rate of thickening growth increased in speed, and the trees reached about 5 cm in average radius and 7.6 m in average height. Figure 3 (c) is an example of _L. rotunda_, _Q. serrata_, and _A. sciadophyloides_. They also increased their growth rates from the second half of 1970s. Their present radiiuses are as large as 6-8 cm, and the average height is 8.2 m although growth seems to be slowing down in recent years. Samples of Fig. 3 (d) are _L. ovalifolia_ and _E. japonica_, the same broadleaf trees as in (c). Average stem radius is about 2 cm, and the height is 2.8 m. They have consistently grown in the lowest layer.

3. Energy balance

Diurnal change of radiation components is shown in Fig. 4. The upper figure is data from the middle layer (7 m from the ground), and the lower one is data from the forest floor (1 m), measured in August 2001. The output voltage was divided by the sensor constant to change the
units to w/m² both for short- and long-wave radiations, and, for long-wave radiation, data were revised by adding the product of the fourth power of dome temperature and Bortzmann's constant. Data were figured after employing 30-minute moving averages. High temperatures continued and no rain was observed throughout the period because Pacific high pressure covered the whole of Japan that week. In the middle layer, downward short-wave radiation (SWd) exceeded 600 w/m² in daytime, and reflected short-wave radiation (SWu) also reached 100 w/m² or more (Fig. 4 (a)). Long-wave radiation had a similar absolute value (LWd=−LWu), and both types of radiation tended to increase a little in daytime and decrease gradually in nighttime. This is an example of the middle of summer, but the parameters were small on the whole because the instruments were shaded by leaves and branches. However, the data from ground surface were even smaller (Fig. 4 (b)), and almost no SW was observed in daytime. Broadleaf trees covered the sky even after large-sized pines withered, so little solar radiation could come down to the forest floor. LWu was also small due to the shade effect, meaning that radiative cooling was restricted. In addition, measurements on cloudy days, which were carried out in the first week of June, showed a similar trend with much smaller values. For example, the maximum SWd in the middle layer was about 400 w/m², SWu did not reach 100 w/m², and all four of the parameters were smoother with no diurnal variation on the forest floor.

Net radiation (RN), which was calculated from \( RN = (SWd + LWd) - (SWu + LWu) \), is shown in Figure 5 with photosynthetically active radiation (PAR). In the middle layer (Fig. 5 (a)), RN tended to depend on SWd. Energy release in nighttime was fairly small, and the cooling effect was weak. PAR, having a wavelength of 400-700 nm which is related to photosynthesis, had also a similar phase to RN. Temporarily, it amounted to 1,200 μE/s/m² at around noon, meaning that sufficient energy for photosynthesis activity was brought to the middle layer. On the forest floor (Fig. 5 (b)), however, both RN and PAR were zero almost throughout each day, showing that there was not much sunshine. In the case of cloudy days in June, the maximum RN was about 200 w/m², and PAR was 1,000 μE/s/m² in the middle layer. They were smaller than those in August. Also, they were completely zero.
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at the forest floor throughout each day.

![Energy balance measurements](image)

**Fig. 4.** Energy balance measured in (a) middle layers and (b) the forest floor on clear days in mid-August. SWd: downward short-wave radiation, SWu: upward short-wave radiation, LWd: downward long-wave radiation, LWu: upward long-wave radiation.

![Diel change of net radiation](image)

**Fig. 5.** Diurnal change of net radiation (RN) and photosynthetically active radiation (PAR) in middle layers (a) and on the forest floor (b).

### 4. Percentage of vessel area

Images of *Q. serrata*, a tree which is now increasing thickening growth, and *I. crenata*, whose growth has been stagnant, are shown in Fig. 6. The direction of radial growth is from right to left in the figure. Wood tissue of broadleaf trees consists of vessel elements, libriform wood fiber, and axial and ray parenchyma. Ray parenchyma, which are recognized as whitish lines, and fibers, which are blackish cells in the back, are common in both of the species, but the distribution of axial parenchyma is a tangential arrangement in the former species, while it is scanty paratracheal parenchyma in the latter. Vessel arrangement is also different; that is, the former is ring-porous wood in which large-sized vessels which are formed in the beginning of growth season and then change to small-sized vessels, and the latter one is a diffused arrangement with no variation of vessel size during the growth season. Also a few vessels in *I. crenata* are united in the radial direction, this being called radial pore multiple (Shimaji et al., 1976, Ito, 1995, 1998). There is not a large difference in tree age (*Q. serrata*: 41 year-old, *I. crenata*: 39 year-old), but the tree heights are 7.5 m and 1.0 m, and D₀ (diameter at ground surface) are 95 mm and 60 mm, respectively. When comparing the percentages of vessel areas between 1969 and 1999, they increased from 6.18% in 1969 to 14.73% in 1999 for *Q. serrata*, while they did not largely change for *I. crenata* (1969: 5.49%, 1999: 5.99%). The largest vessel diameters and circumferences were also larger in the outside tree-rings for *Q. serrata*, but they were almost equal for *I. crenata*. Likewise, when comparing *I. rotunda*, which have
a diffused arrangement of radial pore multiple (Ito, 1998), and *E. japonica*, which also have a diffused arrangement (Ito, 1996), the percentages were 4.90% in 1969 and 13.38% in 1999 for *I. rotunda*, while they were 7.25% in 1969 and 7.81% in 1999 for *E. japonica* in which the age, height, and $D_{10}$ of *I. rotunda* were 42 years old, 8 m, and 15 cm, and those of *E. japonica* were 41 years old, 3.5 m, and 4.5 cm, respectively.

*Quercus serrata*

![1969 and 1999 images of *Quercus serrata*](image)

*Ilex crenata*

![1969 and 1999 images of *Ilex crenata*](image)

Fig. 6. Images of stem cross sections of *Quercus serrata* and *Ilex crenata* in 1969 and 1999.

5. **Dead biomass of red pines**

Red pine is a dominant species and the individual biomass is the largest among tree species in the Satoyma forests of the Sanyo District. Therefore, the dieback has a great influence on trees growing beneath. By measuring the size in three belt-transects and taking photos from a hot-air balloon, this research estimated the percentage of red pines that had withered. Fieldwork was conducted in Site B because Site A is an area where flights are prohibited. Three hundred red pines were classified: 35 were found to be living individuals, 73 were standing decayed ones, and 192 were stem broken/fallen ones. The mortality, which was 88.3%, was similar to that in Site A (89.3%). TH (tree height) of standing decayed individuals was $13.76 \pm 3.33$ m, and $D_{10}$ (stem diameter at a height of 10 cm) was $22.83 \pm 7.46$ cm. The regression equation was $TH=0.276 \cdot D_{10}^{0.722}$ ($R^2=0.97$). Here, it is supposed that standing decayed pines maintain the same tree height as just before their deaths. $D_{10}$ is the diameter in which the bark is included because it has not been removed even in the dead individuals. When substituting $23.58 \pm 6.93$ cm to the regression equation, the stem diameter of broken/fallen red pines, the tree height was estimated to be $14.08 \pm 3.04$ m. From a hot-air balloon, it was confirmed that there were 8,040 standing decayed pines in
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0.71 km². This means that the number of stem broken and fallen pines existing in the forest amount to 21,175 although they are all impossible to see from the balloon. Then, the dead biomass was evaluated from this data, as was the allometric equation for stems (W₁ = 0.02182(D₁₀⁶/TH)⁰.⁵⁴⁸, kg) and branches (W₂ = 0.01262(D₁₀⁶/TH)⁻¹.⁵⁸², kg) of red pine (Nakane et al., 1984). Table 2 shows the dead biomass of standing decayed, stem broken, and fallen individuals. Considering the standard deviation of TH and D₁₀⁶, they were calculated in three cases. As a result, it was 7,718 t/0.71 km² in the maximum case, and was 1,565 t/0.71 km² in the minimum one. They are equivalent to 10,870 t/km² and 2,204 t/km², respectively.

Table 2. Dead biomass of red pines in Site B (0.71 km²) estimated into three cases because standard deviation of tree height of standing decayed individuals was considered when estimating the tree height of stem broken/fallen individuals.

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<tr>
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<th>Stem broken, Fallen</th>
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<tr>
<td>Max</td>
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<td>5,618</td>
<td>7,718</td>
</tr>
<tr>
<td>Avg</td>
<td>1,007</td>
<td>2,887</td>
<td>3,894</td>
</tr>
<tr>
<td>Min</td>
<td>569</td>
<td>1,196</td>
<td>1,565</td>
</tr>
</tbody>
</table>

DISCUSSION

After red pine forests came to be left untouched because of the use of advanced fossil fuels in the 1960s, the dieback started in the 1970s, and it became conspicuous in the 1980s. More than 70% of red pines have withered in the last 20 years, and the withering is expanding 1,000 to 1,800 ha annually (Shiratsuki et al., 1999). The direct cause is blight disease (Kiyohara and Tokushige, 1971), however, a statistical significance was detected that the most damaged areas are distributed in non-management forests (Shiratsuki et al., 1999). Kamada and Nakagoshi (1991) pointed out that the disease started from the abandonment of forest management; that is, leaves and branches, which had for centuries been removed from the forest floor to make fuel, overaccumulated so that the soil became too fertilized. Another group explains it as a decrease in vigor caused by air pollution (Nakane et al., 2000). But in any case, in consequence, broadleaf trees are now growing rapidly.

In the quadrant of Site A, 13 broadleaf species have been found. All of them are familiar to Saijo Basin (Fujiiwa, 1996). However, most species have not yet reached their potential height. For example, it is known that L. rotundifolia should reach about 10 m (Hagiwara, 1997), but in this quadrant more than 40% of individuals were smaller than 5 m. It is said that the potential height of Q. serrata is 17-18 m, but more than 70% were smaller than 10 m. In the case of A. sciadopityoides (potential height: 15 m), more than 90% were smaller than 10 m. Rhus sylvestris (10 m) were all smaller than 5 m. Both Ilex aquifolium and Styrax japonica (10 m) were all smaller than 10 m, although the number of individuals is few. Cedars also have not reached their natural heights. These species have accelerated their growth rapidly since the second half of the 1970s (Fig. 3), and the trend will continue into the foreseeable future. On the other hand, the potential heights of the other understory species are about 5 m, and they have already reached that height. Concerning future succession, Kamada and Nakagoshi (1991) estimated that species of Fagaceae such as Q. serrata and Quercus variabilis would be predominant. Shiratsuki et al. (1999) pointed out that red pines will not recover to previous levels,
and *Q. serrata* will occupy places where it is established like a patch, but other places will be changed to all mixed forests with no red pine. The latter researchers estimated that medium-sized trees such as *Symlocos racemosa*, *Ilex pendunculosa*, and *A. scidophylloides* would increase in numbers.

The withering of red pines helped spur the growth of medium-sized individuals. Taking into consideration Blackman's Limiting Factor Theory—which says that if a limiting factor exists among water, light, temperature, and CO₂, then photosynthesis is regulated by the lowest level even if the other three factors are sufficient (Kobayashi, 1982)—medium-sized trees such as cedar, *I. rotunda*, *A. scidophylloides*, and *Q. serrata* could not help remaining in the forest because of insufficient lighting conditions. However, lighting stress was reduced after red pines stood decayed and the stems broke or fell (Fig. 4 (a), Fig. 5 (a)). Summertime downward short-wave radiation usually exceeds 1,000 w/m² on the naked ground. The radiation at the middle layer (about 600 w/m²) is still small, but photosynthetically active radiation temporarily surpasses 1,200 μE/m². Such a value would not have been recorded when red pines covered the above. It is believed that the other three factors did not change drastically except for water conditions in 1994. In that year, rainfall from June to July was only 159 mm, and the number of rainy days was only 15 in the whole rainy season. As a result, the tree-ring width of this year was equally restricted in all species due to water stress.

On the other hand, lighting conditions near the forest floor did not improve even after the withering of red pines (Fig. 4 (b), Fig. 5 (b)). Not only understory species whose potential height is small but also small-sized red pines have been left stressed by a lack of light (Fig. 3 (d)).

The absorption of water is indispensable with respect to supporting rapid extension growth, and such trees have to improve water conductivity to pump up water against gravity to leaf layers. This results in the enlargement of vessel areas. Tyree and Ewers (1991) applied the Hagen-Poiseuille's Law of fluid dynamics to sap flow, and presented a theoretical hydraulic conductivity of sap (Kₕ, kgm/s/MPa) to be Kₕ = (πρ / 128η)(Σdᵢ⁴). Here, ρ is the density of sap, η is the dynamic viscosity of fluid, d is the diameter of the cylinder, and n is the number of cylinders. For trees, ρ is the density of sap, d is the vessel diameter, and n is the number of vessels in the tree-ring. It is found from this equation that Kₕ is regulated by d, and Kₕ is proportional to the fourth power of d. N is also related, but d contributes more to the change of Kₕ. Vessel area is a product of n and d². If it is large, the efficiency of absorbing sap increases, while if it is small the efficiency drops. Tree height is influenced by vessel area. In the vertical movement of sap, water potential of about 0.1 bar must be maintained within a stem because not only hydrostatic pressure within the tissue but also gravitational potential are added (Fitter and Hay, 1981). Therefore, it is necessary to increase hydraulic conductivity to cope with pressure gradients. In the present study, it was found that tree-ring widths of *Q. serrata* largely increased after the 1980s (Fig. 6). There is no doubt that extension growth also followed. The increase of vessel area was brought about to support the elongation. Tsuchiya *et al.* (2002) pointed out that the relationship between tree height and percentage of vessel area regresses in the same curve regardless of species. In this study, understory species such as *E. japonica* and *I. crenata* showed little change either in tree height or vessel area. This is because those species do not have a natural strategy to extend themselves, and because they have had inadequate amount of light even after the dieback of red pines.

On June 29, 1999, there were over 50 mm/h of heavy rain, and debris flows took place in 46 places in the whole basin. Rainy days had been
continuing since the end of May, and soil moisture had already been saturated. The localized torrential downpour occurred under these situations, and pushed away earth and sand as surface runoff. It is surmised that the soil texture, which is weathered granite, exacerbated the disaster (Kaitori et al., 1999, Ushiyama et al., 1999). Besides meteorological and geological factors, the authors think that a large amount of the dieback of red pines can be induced by debris flow because the kinetic energy in the debris flow is large if the potential energy on the slope is large (Table 2). Decomposition of the root system, accompanied by dieback of aboveground stems, decreases the ability of trees to grasp soil. Nakane and Yamamoto (1983) showed an empirical equation for estimating tensile strength of root systems from the diameter at breast height of stems. According to the equation, the tensile strength is 5 t for a red pine with a diameter of 15 cm, and is 22 t for a 30-cm red pine. Although the diameter used in this study is not the diameter at breast height, D10 of standing decayed, broken, and fallen red pines is about 15-30 cm. If more than 10,000 red pines (km²) die, the improvement of tensile strength is immeasurable. Even if they are substituted with broadleaf trees, it is hardly thought that the strength would be alternated with broadleaf trees because they are still juvenile.

In this study, responses of medium and understory individual trees subjected to the dieback of red pines were investigated in Saijo Basin with respect to lighting stress, thickening growth patterns, and the percentage of vessel area in stem cross sections. Medium-sized trees are accelerating their growth after the amelioration of lighting stress, but are still in a developing stage. The competition between such trees and still-living red pines will be monitored as a future study.

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土谷彰男, 佐久川弘. 広島県西条盆地におけるアカマツの枯死にともなう高木・下層木個体の応答に関する研究.

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