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Ecological and growth characteristics of trees after resumption of management in abandoned substitution forest in Japan

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Abstract

Since the 1950s, secondary (substitution) forests known as Satoyama woods have been abandoned due to changes in human lifestyle. The aim of this study was to investigate the relationships between human activity and substitution forests to better understand the traditional management required to prevent succession to evergreen forest. An objective was to identify the tree species, their numbers of trunks (NT), and the basal area (BA) (collectively, the stand density) in the woods today, half a century after people abandoned the substitution forests. Another goal was to compare, over a six-year period, the figures for total NT, BA, and the number of living, dead or fallen trunks between an abandoned substitution forest (a control plot) and a mown plot. NT decreased from 700 trunks/ha to 600 trunks/ha on the control, and from 600 trunks/ha to 400 trunks/ha on the mown plot at ground level over six years. The total BA increased annually on the control plot but decreased from 48m^2/ha to 38m^2/ha on the mown plot over six years. Many hydrophytes (*Alnus japonica*, etc.), *Quercus serrata*, and other trees species were found dead on the mown plots. All *Quercus myrsinaefolia* (evergreen trees) were still alive by the sixth year. These results demonstrate that the vegetation in these forests succeeded to Quercetum myrsinaefoliae, Tyoische Subass., which is therefore shown as the potential vegetation of succession over this timescale. If it is desired to maintain the traditional vegetation type, then the study suggests that it is necessary to manage the substitution forest. This is in order to prevent succession to evergreen forest and can be achieved by cutting *Pleioblastus chino*, climbing plants, and shade plants (evergreen trees).

Introduction

Japan has diverse climatic regions ranging from subtropical to subpolar, and the precipitation is high. There were many substitution forests known as Satoyama woods (Morimoto 2011; Yokohari and Bolthouse 2011), consisting of *Quercus serrata* Thunb. *ex* Murray, *Quercus acutissima* Carruthers, *Prunus jamasakura* Sieb. *ex* Koidz., and other deciduous tree species, and historically they were actively exploited by local people. The timber was used as substrate for growing shiitake (mushroom), for making charcoal, and in both construction and furniture making. Fallen leaves were taken as fertilizer or fuel, and certain roots and leaves of shrubs and herbaceous plants were used for food and medicine, such as *Erythronium japonicum* Decne., *Lilium auratum* Lindley, *Allium victorialis* L. subsp. *platyphyllum* Hultén (Shibata 1957). Until the 1950s, the plants in the substitution forests were managed sustainably and there was a careful balance maintained between nature and human activity. Since then however, humans abandoned the Satoyama woods as a result of changing lifestyles and increased consumption of fossil fuels. Consequently, the woods have undergone successional changes.

The Satoyama woods are located in suburbs situated between mountainous regions and urban areas, and they have a unique biodiversity. Particular plant species forming distinctive vegetation were found on each type of terrain, from mountains, hills, forests, paddy fields, streams, irrigation ponds to ridges (Okutomi et al. 1976). However, the open spaces of the Satoyama woods have since been fragmented and became isolated through urbanization and human activities (Iida and Nakashizuka 1995; Stéphanie et al. 2007). Changes were observed, for example after humans abandoned the substitution forest, many *Pleioblastus chino* (Franch. & Savat.) Makino began to grow at the forest floor level in the Kanto area. Certain tree species disappeared and were displaced by *P. chino*, such as *Callicarpa mollis* Sieb. *et* Zucc., and *Lonicera gracilipes* Miq. var. *glabra* Miq. (Nakajima et al. 2016). Nakajima et al. (2016) showed that in the mown *P. chino* site, the fraction of absorbed photosynthetically active radiation was significantly lower and the species diversity was significantly higher than those for the abandoned (control) site. Without human management the vegetation in these areas succeeds to become to Quercetum myrsinaefoliae, Tyoische Subass. and now reflects the potential natural vegetation (Miyawaki et al. 1981a).

For the substitution forests that have been long abandoned, there are many reports on the influence of human management on the herbaceous (Hosogi et al. 2001; Kobayashi et al. 1999). Nevertheless, there is little information on the tree species that appear, grow, or disappear in the substitution forest themselves. In the present study, to better understand the traditional management necessary to prevent succession to evergreen forest, we investigated two aspects of the relationships between human activity and substitution forests. First, we investigated the types of tree species that occur in a long-abandoned substitution forest together with the trunk stand density (number of trunks, basal area) and the annual growth rings. Second, over a six-year period, starting in 2010, we compared abandoned substitution forest in terms of stand density (number of trunks, basal area), and the number of living, dead or fallen trunks, to an area where traditional management techniques were resumed. The techniques applied were the cutting of *P. chino*, shade plants, climbing plants, and others.

Study site and Methods

Study site

The experiment was conducted over an 11-ha area in the Hayano Special Green Space Conservation Districts, southern Tama Hill, Aso-ku, Kawasaki-city, Kanagawa Prefecture, Japan. This is located at Lat. 35°34’30’’ N and Long. 139°31’ 6” E, and is 50-80 m above sea level (Fig. 1). In the past, the site was used for wood and food by local communities. The surrounding areas have been deforested and Tama New Town was built, consisting of many apartments, houses, and shops. The forest has been fragmented since the 1960s. Researchers published many reports about Tama New Town and the surrounding area since following urbanization many native plants rapidly disappeared (Dokiya and Ogura 2001).

Methods

All plots were set up in the same direction and at the same slope in the Hayano Special Green Space Conservation Districts. The total area of study was 8,700m^2, of which 2,000 m^2 was allocated to the control plots and 6,700 m^2 was allocated to the mown plots (Figs.2 and 3). The control plots were set up in a part of the substitution forest that had been abandoned since the 1950s. No human intervention occurred during the study.

On the mown plots, stand of *P. chino*, which had covered the entire forest floor, were manually cut with traditional reaping hooks at 3-5cm height. No machines were used. Mowing of *P. chino* or other species was done in early summer of every year starting in July, 2010. Dead and fallen trees, shade plant seedlings, climbing plants, and the trunk base tillers of *Celtis sinensis* Pers. var. *japonica* (Planch.) Nakai, *Q. acutissima*, *Q. serrata*, *P. jamasakura* and *Styrax japonica* Sieb. *et* Zucc. were also manually cut at 10-30 cm height on ground level. The tree species that were cut down in 2010 are shown in Appendix 1.

Just after forest management was resumed in 2010, the annual rings of *Q. serrata*, and two shade plants (*Quercus myrsinaefolia* Blume and *Eurya japonica* Thunb.) were counted. Trunk circumferences were measured every year at 1.3 m above ground level. These points were marked with two nails in the bark. For tree species like *Q. serrata* with multiple trunks, we measured the annual rings at the base of a trunk. The basal area (BA) was calculated from the trunk circumference.

To determine the impact of abandoning substitution forests on species diversity and stand density, (1) species types and stand density (NT: number of trunks; BA: basal area), and (2) number of annual rings in tree representative species were studied. The latter were *Q. serrata* and two shade plants (*Q. myrsinaefolia* and *E. japonica*). This was just after the cutting down of *P. chino*, dead and fallen trees, shade plants seedlings, and climbing plants in 2010. The management followed a long period of human abandonment of the substitution forest. We then compared the total NT, BA, the number of living, dead, and fallen trunks on mown and control plots over a six-year period after the resumption of traditional management practices in the abandoned substitution forest.

Results and Discussion

1. Species types, stand density, and number of annual rings in trees growing after abandonment of substitution forest for half a century

(1) Species types and stand density (NT and BA)

There were twenty-eight tree species distributed in the abandoned substitution forest. Most of these were temperate deciduous trees, including *Carpinus tschonoskii* Maxim., *Alnus japonica* (Thunb.) Steud., *Q. acutissima*, *Q. serrata*, and others. There were also evergreen conifers, including *Abies firma* Sieb. *et* Zucc. and *Cryptomeria japonica* (L. fil.) D. Don, and evergreen broad-leaved trees, including *Quercus glauca* Thunb. *ex* Murray, *Q. myrsinaefolia*, *Ligustrum japonicum* Thunb., and *Ligustrum lucidum* Ait. (Fig. 4). *C. tschonoskii*, *Quercus acutssima*, *Q. serrata*, *Q. myrsinaefolia*, *Prunus grayana* Maxim., *P. jamasakura*, *S. japonica*, and *A. firma* had larger NT or BA at ground level and 1.3 m height. The unit trunk circumference per one trunk of *S. japonica* was small since the NT was high, while the total BA was low. Unit trunk circumferences of *A. firma* were large since this species has only one trunk, but the total BA was relatively low. BA for all other species were < 0.5 m^2 except for *Q. myrsinaefolia* and *P. grayana*, for which the BA ranged from 0.5 to 1 m^2.

There were large differences in NT between ground level and 1.3 m height for *C. tschonoskii*, *Q. serrata*, *Q. myrsinaefolia*, *Zelkova serrata* (Thunb.) Makino, *P. grayana*, *P. jamasakura*, *Sapium japonicum* (Sieb. et Zucc.) Pax *et* K. Hoffm., *Meliosma myriantha* Sieb. *et* Zucc., *S. japonica*, *L. lucidum*, and *Fraxinus lanuginosa* Koidz. f. *serrata* (Nakai) Murata (Fig. 4). These species are able to produce buds at the tree base after the trunk is cut. The evergreen conifers (*A. firma* and *C. japonica*), the deciduous tree (*A. japonica*, *Q. glauca*, *C. sinensis* var. *japonica*, *Magnolia praecocissima* Koidz., *Rhus trichocarpa* Miq., *Sambucus racemosa* L. subsp. *sieboldiana*), and the evergreen broadleaf *L. japonicum* had single trunks at 1.3 m height and ground level.

The BA of *Q. serrata* was greater than that of *Q. acutissima*. These species belong to the family Fagaceae. Many *Q. serrata* individuals had several trunks each with one root, but most *Q. acutissima* had only a single trunk with one root. Yanagiya et al. (1966) also suggest that *Q. serrata* has been used extensively for charcoal, or produces multiple trunks more readily than does *Q. acutissima*. *P. jamasakura*, *Prunus buergeriana* Miq., and *P. grayana* had several trunks each with one root. They are members of the family Rosaceae. *P. jamasakura* had a far greater NT than either *P. buergeriana* or *P. grayana* at ground level.

The species with the largest BA (basal area) were *Q. serrata*, *C. tschonoskii*, and *P. jamasakura*. In terms of their histories of utilisation, most of the tree species distributed in Satoyama woods were used to make charcoal. *A. firma*, *C. japonica*, *Z. serrata*, and *F. lanuginosa* f. *serrata* were used for building materials and furniture. Oil was pressed from the seeds of *S. japonicum* (Sugimoto 1965). The leaves of *Magnolia obovata* were used as food covers or plates. The leaves of *Kalopanax pictus* (Thunb.) Nakai were used to cover foods, and its wood was used to make furniture and construction materials (Kurata 1975). At the onset of swidden agriculture, with land cleared for cultivation as arable by a slash-and-burn method, farmers determined the best plots on which to produce crops (Sasaki 1972). *A. japonica* plants were used as indicators for preferred swidden sites because they possess root-nodule bacteria and hence have raised levels of available nitrogen in the soil (Nomoto 2008). *M. myriantha*, *Clethra barbinervis* Sieb. et Zucc., and *S. japonicum* are seldom observed in urban or suburban areas (Flora-Kanagawa Association 2001). They are sensitive to pollution or other factors and serve as important environmental indicator species in developed area.

P. chino eventually covered the entire forest floor. There were also many shade plants such as *Trachycarpus fortunei* (Hook.) H. Wendl., *Q. glauca*, *Q. myrsinaefolia*, *Ilex integra* Thunb., *L. japonicum*, *E. japonica*, *Nandina domestica* Thunb., *Mahonia japonica* (Thunb.) DC., *Ilex crenata* Thunb., *Elaeagnus umbellata* Thunb., *Fatsia japonica* (Thunb.) Decne. *et* Planch., *Aucuba japonica* Thunb., *Ardisia crenata* Sims and *Osmanthus heterophyllus* (G.Don) P.S.Green as well as climbing plants like *Pueraria lobate* (Willd.) Ohwi, *Wisteria floribunda* (Willd.)DC., *Hedera helix* L., and *Trachelospermum asiaticum* (Sieb. *et* Zucc.). *W. floribunda* had grown to 0.28 m trunk circumference and it, along with *T. asiaticum* had grown around and strangled other trees. Many large climbing made it difficult to cut down dead trees. There were also many *Morus australis* Poir. and *Morus alba* L. seedlings; these are used as food for cultivating silkworm (*Bormbyx mori*). Many plants in the forest located near urban areas originated outside the forest (Stephanie et al. 2007; Simith et al. 2006). In 2010, as per the methods described in Appendix 1, *P. chino*, a shade plant, and the seedlings of some deciduous trees including *C. sinensis* var. *japonica*, *Aralia elata* (Miq.) Seemann, *Rosa multiflora* Thunb., *K. pictus*, *C. mollis*, and *L. gracilipes* var. *glabra* were cut down.

Forest floor (understory) species were not investigated in detail. However, these included herbaceous plants like *Ophiopogon japonicus* (L. fil.) Ker-Gawl., *Carex sachalinensis* Fr. Schm. var. *alterniflora* (Franch.) Ohwi, *Lycoris sanguinea* Maxim., *Cymbidium goerningii* (Reichb. fil.) Reichb. fil., *C. nipponicum* (Franch. *et* Savat.) Makino, *Ajuga yezoensis* Maxim. var. *tsukubana* Nakai, *Ajuga nipponensis* Makino, or

Salvia nipponica Miq., which were found at the slope or the base. There were also some rare species present, such as *Calanthe discolour* Lindl., *Cephalanthera falcata* (Thunb.) Blume, *Cephalanthera longibracteata* Blume, and *Lecanorchis nigricans* Honda. (Orchidaceae) are classified as Threatened - Vulnerable, by the Japanese Ministry of the Environment. *L. nigricans* and *C. longibracteata* are rare species in Kanagawa prefecture. *Heterotropa muramatsui* (Makino) F. Maek. var. *tamaensis* (Makino) F. Maek. also appear on the Red List (Kanagawa Prefectural Museum of Natural History 2006). Ecological studies of these species are currently in process.

(2) Number of annual rings of three representative species

Annual rings, trunk circumferences, and the relationships between these two parameters were measured in *Q. serrata*, *E. japonica*, and *Q. myrsinaefolia*. The latter were found in great abundance after felling *P. chino*, the shade plants, and the climbing plants.

E. japonica had small trunk circumferences, but they had far more annual rings than did either *Q. myrsinaefolia* or *Q. serrata* (Fig. 5). Fig. 6 shows the number of annual rings and the tree age or the approximated seed germination year in ten-year intervals for the three species. The number of annual rings in *Q. serrata* ranged from 60 to 11 (seeds germinated between 1951 and 2000), and in both *E. japonica* and *Q. myrsinaefolia* they ranged from 40 to 1 (seed germinated between 1971 and 2011). There were many *E. japonica* and *Q. myrsinaefolia* individuals with fewer than forty year annual rings. *Q. serrata* (deciduous tree) had many more annual rings than did either *E. japonica* or *Q. myrsinaefolia* (evergreen trees). Therefore, these species had germinated and begun to grow in the abandoned forest sometime in the 1970s. This was when human activity (management) must have ceased there. The Satoyama woods substitution forest initially consisted of deciduous trees, which were then succeeded by evergreen broadleaf species after the forest was no longer to used or managed in southern Japan (Azuma et al. 2014). Miyawaki et al. (1981b) showed that the vegetation in this area consisted of Quercetum myrsinaefoliae, Subass. von Abies firma, while the substitution vegetation was Quercetum acutissimo-serratae. It was shown to be Quercetum myrsinaefoliae, Tyoische Subass., and this seems to be the natural successional vegetation (Miyawaki et al. 1981a) after human activity ceased in this forest.

There are relatively few understory species below evergreen broadleaf trees (Okubo et al. 2005). Traditional management such as landscaping, which has not been practiced there since 1950s, would be necessary if it was desired to restore the forest to its earlier condition.

2. Changes of total NT, BA, and number of living, dead, or fallen trunks six years after resumption of traditional management in abandoned substitution forest

(1) Changes of total NT and BA over six years

As shown Fig. 7, on the control plot in 2010, the total NT was 1,000 trunks/ha at 1.3 m height (1.3H) and 700 trunks/ha at ground level (GL). By 2016, the numbers decreased to 800 trunks/ha and 600 trunks/ha, respectively. The total NT at GL changed only slightly from 2013 to 2016 on the control plots. On the mowing plots, many trees were dead or fallen one year after cutting *P. chino,* the climbing plants, and the shade plants. Starting in 2011, NT decreased gradually for the next five years. In 2010, NT was 900 trunks/ha at 1.3H and 550 trunks/ha at GL. By 2016, NT decreased to 600 trunks/ha (1.3H) and 400 trunks/ha (GL). The ideal NT was reported by Shigematsu in the text edited by Sigematsu (1987) when they proposed that 600-800 trunks/ha in the ideal trunk density for Satoyama woods. It is difficult to judge the ideal NT, since the data are differ with geographical condition, climate zone or tree age. However, we think the 600 trunks/ha (1.3H) and 400 trunks/ha (GL) are appropriate in this area.

The BA of *Q. serrata* and *P. jamasakura* consisted more than half of the total value (see lower graph in Fig. 8; mesh and black mark). As shown in the upper graph in Fig. 8, the control plot BA increased annually starting in 2010. The mown plot BA decreased from 48 m^2/ha to 36 m^2/ha between 2010 and 2012, but increased to 38 m^2/ha by 2016. Many dead or fallen trees effected on decreasing BA just after cutting *P. chino*, climbing plants, and the shade plant.

In this case, the BA was higher than it was in the deciduous broadleaf secondary forest located in Hyogo Prefecture in western Japan (23.92 m^2/ha), which was abandoned for around seventy years (Azuma et al. 2014). The BA of around 38 m^2/ha is appropriate when NT are 600 trunks/ha (1.3H) and 400 trunks/ha (GL).

(2) Number of living, dead, or fallen trunks

Fig. 9 shows the number of living or dead trunks counted over six years. The lower values on the y-axis represent the total number of dead trunks. Neither *A. firma* nor *Q. myrsinaefolia* individuals were found dead on either the control plot or the mown plots (upper graph in Fig. 9). No *Q. acutissima*, *P. jamasakura*, *P. grayana* or *Cornus controversa* Hemsl. were dead on the control plot. All *K. pictus* on the mown plots were alive, too.

The number of dead trunks in total on the mown plots was higher than that on the control plots except for *Z. serrata* and *K. pictus* (middle graph in Fig. 9). The proportions of the total number of dead trunks for each species on the mown plot over the six years were: *Q. serrata*, and *S. japonicum*, 30%; *Q. acutissima*, *P. grayana* and *P. jamasakura*, 40%; *F. lanuginosa* f. *serrata*, 50%; *S. japonica*, 70%; and *A. japonica*, 100%. Almost no *C. tschonoskii* were found dead on the control plot, but 20% of them were dead on the mown plot. These results showed that subtle changes in moisture content after cutting *P. chino*, shade plants, and climbing plants affected the growth of the trees in this forest.

Sixteen per cent of the *P. jamasakura* were dislodged due to strong winds (typhoon), despite their large trunk circumference (up to 0.9m). This is the same proportion as the number of dead trunks (Fig. 9). *P. jamasakura* has shallow roots and could not compete for space with *P. chino*, shade plants, or others.

The climax vegetation in this area consisted of Quercetum myrsinaefoliae, Subass. von Abies firma (Miyawaki et al. 1981b). These deciduous trees either fall or die easily soon after cutting *P. chino*, climbing plants, and the shade plants.

Conclusion

The conservation of native and rare plant species in urban areas and suburbs is of vital importance. However, with sites unmanaged, forest floor plants are being displaced by evergreen trees like *Q. myrsinaefolia*. Since the deciduous Satoyama woods are being succeeded by evergreens, if it is desired to maintain the traditional woods, it is necessary to manage the substitution forest. This would be by cutting out the successional species such as *P. chino*, shade plants (evergreen trees), and the climbing plants. Further research is required to determine more effective management strategies if it is considered desirable to maintain the traditional ecologies and values of the Satoyama woods.

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Figure and Appendix legends

Fig. 1 Study area (black square)

Fig. 2 Experimental plots of black square, modified by Topographic Map of Japan, Hayano Special Green Space Conservation Districts published from Kawasaki city. Number represent contour line, C: area of control plots; M: area of mown plots

Fig. 3 Experimental plots. Mowing (foreground) and Control (background)

Fig. 4 Total number of trunks (NT) at 1.3 m height (white bar), and at ground level (black bar) on cutting/mown plot, and BA (basal area, m^2/ha, dotted line) in 2010, just after cutting *Pleioblastus chino*, shade plants, climbing plants, etc. Total NT * at 1.3 m height and at ** ground level for *Quercus serrata*. #: evergreen conifer; parentheses: evergreen broad leaf; no symbol: temperate deciduous tree

Fig. 5 Relationships between number of annual rings and trunk circumference for *Quercus serrata* (triangle and line), *Quercus myrsinaefolia* (black square and large dotted line) and *Eurya japonica* (circle and small dotted line)

Fig. 6 NT interval of tenth annual rings (years) for *Eurya japonica* (square and small dotted line), *Quercus serrata* (line), and *Quercus myrsinaefolia* (large dotted line). The reported value of 189 annual rings of for *Q. serrata* was derived from the average of twenty-one trees

Fig. 7 Total stand density, number of trunks (NT) during six years. Line represents control plot and dotted line represents mown plot, respectively. Black circles represent NT at 1.3 m height. Both line and dotted line without black circle represent NT at ground level

Fig. 8 Changes in basal area (BA) (m^2/ha), Upper area: control plot; Lower area: mown plot.

▦: *Quercus serrata*, ■: *Prunus jamasakura*, □ with gray: *Carpinus tschonoskii*, ▨: *Quercus acutissima*, □with dots: *Abies firma*, ▧: *Prunus grayana*, ▥: *Styrax japonica* and □: others.

Fig. 9 Proportion of dead trees. x-axis: year; y-axis: relative numbers of dead trees (1.0 NT) as of 2010. Values at bottom represent dead tree counts between 2010 and 2016 on control plots (line) and on mown plots (dotted line). All tree species were present on both control and mown plots except for *Alnus japonica* and *Sapium japonicum.* Numbers in parentheses after botanical names indicate total number of samples. * *Abies firma* (1 and 6); *Quercus myrsinaefolia* (19 and 5) on control and mown plots, respectively; *Quercus acutissima* (8) on control plot. ** *Prunus grayana* (2); *Prunus jamasakura* (2); *Cornus controversa* (1) on control plot, and *Kalopanax pictus* (3) on mown plots. ***16% trunks were dead by fallen at root base

Appendix 1 Species, number of trunks, and trunk circumferences (from highest to lowest) of seedlings, young, climbing, dead, and shade plants cut down on mown plots at the onset of forest management in 2010.

Many seedlings of all plant species were present besides those that were cut down. For *Quercus serrata*, 189 dead trunks were felled. -: no data. *H= height.