

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

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

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33 **Abstract**

34 Since the 1950s, secondary (substitution) forests known as Satoyama woods have been  
35 abandoned due to changes in human lifestyle. The aim of this study was to investigate  
36 the relationships between human activity and substitution forests to better understand  
37 the traditional management required to prevent succession to evergreen forest. An  
38 objective was to identify the tree species, their numbers of trunks (NT), and the basal  
39 area (BA) (collectively, the stand density) in the woods today, half a century after  
40 people abandoned the substitution forests. Another goal was to compare, over a six-year  
41 period, the figures for total NT, BA, and the number of living, dead or fallen trunks  
42 between an abandoned substitution forest (a control plot) and a mown plot. NT  
43 decreased from 700 trunks/ha to 600 trunks/ha on the control, and from 600 trunks/ha to  
44 400 trunks/ha on the mown plot at ground level over six years. The total BA increased  
45 annually on the control plot but decreased from 48m<sup>2</sup>/ha to 38m<sup>2</sup>/ha on the mown plot  
46 over six years. Many hydrophytes (*Alnus japonica*, etc.), *Quercus serrata*, and other  
47 trees species were found dead on the mown plots. All *Quercus myrsinaefolia* (evergreen  
48 trees) were still alive by the sixth year. These results demonstrate that the vegetation in  
49 these forests succeeded to *Quercetum myrsinaefoliae*, Tyoische Subass., which is  
50 therefore shown as the potential vegetation of succession over this timescale. If it is  
51 desired to maintain the traditional vegetation type, then the study suggests that it is  
52 necessary to manage the substitution forest. This is in order to prevent succession to  
53 evergreen forest and can be achieved by cutting *Pleioblastus chino*, climbing plants, and  
54 shade plants (evergreen trees).

## 55 **Introduction**

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

71 The Satoyama woods are located in suburbs situated between mountainous regions  
72 and urban areas, and they have a unique biodiversity. Particular plant species forming  
73 distinctive vegetation were found on each type of terrain, from mountains, hills, forests,  
74 paddy fields, streams, irrigation ponds to ridges (Okutomi et al. 1976). However, the  
75 open spaces of the Satoyama woods have since been fragmented and became isolated  
76 through urbanization and human activities (Iida and Nakashizuka 1995; Stéphanie et al.  
77 2007). Changes were observed, for example after humans abandoned the substitution  
78 forest, many *Pleioblastus chino* (Franch. & Savat.) Makino began to grow at the forest  
79 floor level in the Kanto area. Certain tree species disappeared and were displaced by *P.*  
80 *chino*, such as *Callicarpa mollis* Sieb. *et* Zucc., and *Lonicera gracilipes* Miq. var.  
81 *glabra* Miq. (Nakajima et al. 2016). Nakajima et al. (2016) showed that in the mown *P.*  
82 *chino* site, the fraction of absorbed photosynthetically active radiation was significantly  
83 lower and the species diversity was significantly higher than those for the abandoned  
84 (control) site. Without human management the vegetation in these areas succeeds to  
85 become to *Quercetum myrsinaefoliae*, Tyoische Subass. and now reflects the potential  
86 natural vegetation (Miyawaki et al. 1981a).

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

100

## 101 **Study site and Methods**

### 102 **Study site**

103 The experiment was conducted over an 11-ha area in the Hayano Special Green Space  
104 Conservation Districts, southern Tama Hill, Aso-ku, Kawasaki-city, Kanagawa  
105 Prefecture, Japan. This is located at Lat. 35°34'30" N and Long. 139°31' 6" E, and is  
106 50-80 m above sea level (Fig. 1). In the past, the site was used for wood and food by  
107 local communities. The surrounding areas have been deforested and Tama New Town  
108 was built, consisting of many apartments, houses, and shops. The forest has been  
109 fragmented since the 1960s. Researchers published many reports about Tama New  
110 Town and the surrounding area since following urbanization many native plants rapidly  
111 disappeared (Dokiya and Ogura 2001).

112

### 113 **Methods**

114 All plots were set up in the same direction and at the same slope in the Hayano Special  
115 Green Space Conservation Districts. The total area of study was 8,700m<sup>2</sup>, of which  
116 2,000 m<sup>2</sup> was allocated to the control plots and 6,700 m<sup>2</sup> was allocated to the mown  
117 plots (Figs.2 and 3). The control plots were set up in a part of the substitution forest that  
118 had been abandoned since the 1950s. No human intervention occurred during the study.

119 On the mown plots, stand of *P. chino*, which had covered the entire forest floor, were  
120 manually cut with traditional reaping hooks at 3-5cm height. No machines were used.  
121 Mowing of *P. chino* or other species was done in early summer of every year starting in  
122 July, 2010. Dead and fallen trees, shade plant seedlings, climbing plants, and the trunk  
123 base tillers of *Celtis sinensis* Pers. var. *japonica* (Planch.) Nakai, *Q. acutissima*, *Q.*  
124 *serrata*, *P. jamasakura* and *Styrax japonica* Sieb. et Zucc. were also manually cut at  
125 10-30 cm height on ground level. The tree species that were cut down in 2010 are  
126 shown in Appendix 1.

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

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

142

## 143 **Results and Discussion**

144

### 145 **1. Species types, stand density, and number of annual rings in trees growing after** 146 **abandonment of substitution forest for half a century**

147

#### 148 **(1) Species types and stand density (NT and BA)**

149 There were twenty-eight tree species distributed in the abandoned substitution forest.  
150 Most of these were temperate deciduous trees, including *Carpinus tschonoskii* Maxim.,

151 *Alnus japonica* (Thunb.) Steud., *Q. acutissima*, *Q. serrata*, and others. There were also  
 152 evergreen conifers, including *Abies firma* Sieb. et Zucc. and *Cryptomeria japonica* (L.  
 153 fil.) D. Don, and evergreen broad-leaved trees, including *Quercus glauca* Thunb. ex  
 154 Murray, *Q. myrsinaefolia*, *Ligustrum japonicum* Thunb., and *Ligustrum lucidum* Ait.  
 155 (Fig. 4). *C. tschonoskii*, *Quercus acutissima*, *Q. serrata*, *Q. myrsinaefolia*, *Prunus*  
 156 *grayana* Maxim., *P. jamasakura*, *S. japonica*, and *A. firma* had larger NT or BA at  
 157 ground level and 1.3 m height. The unit trunk circumference per one trunk of *S.*  
 158 *japonica* was small since the NT was high, while the total BA was low. Unit trunk  
 159 circumferences of *A. firma* were large since this species has only one trunk, but the total  
 160 BA was relatively low. BA for all other species were  $< 0.5 \text{ m}^2$  except for *Q.*  
 161 *myrsinaefolia* and *P. grayana*, for which the BA ranged from 0.5 to  $1 \text{ m}^2$ .

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

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

179 The species with the largest BA (basal area) were *Q. serrata*, *C. tschonoskii*, and *P.*  
 180 *jamasakura*. In terms of their histories of utilisation, most of the tree species distributed  
 181 in Satoyama woods were used to make charcoal. *A. firma*, *C. japonica*, *Z. serrata*, and *F.*  
 182 *lanuginosa* f. *serrata* were used for building materials and furniture. Oil was pressed

183 from the seeds of *S. japonicum* (Sugimoto 1965). The leaves of *Magnolia obovata* were  
 184 used as food covers or plates. The leaves of *Kalopanax pictus* (Thunb.) Nakai were used  
 185 to cover foods, and its wood was used to make furniture and construction materials  
 186 (Kurata 1975). At the onset of swidden agriculture, with land cleared for cultivation as  
 187 arable by a slash-and-burn method, farmers determined the best plots on which to  
 188 produce crops (Sasaki 1972). *A. japonica* plants were used as indicators for preferred  
 189 swidden sites because they possess root-nodule bacteria and hence have raised levels of  
 190 available nitrogen in the soil (Nomoto 2008). *M. myriantha*, *Clethra barbinervis* Sieb.  
 191 et Zucc., and *S. japonicum* are seldom observed in urban or suburban areas  
 192 (Flora-Kanagawa Association 2001). They are sensitive to pollution or other factors and  
 193 serve as important environmental indicator species in developed area.

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

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



215 *Salvia nipponica* Miq., which were found at the slope or the base. There were also some  
 216 rare species present, such as *Calanthe discolor* Lindl., *Cephalanthera falcata* (Thunb.)  
 217 Blume, *Cephalanthera longibracteata* Blume, and *Lecanorchis nigricans* Honda.  
 218 (Orchidaceae) are classified as Threatened - Vulnerable, by the Japanese Ministry of the  
 219 Environment. *L. nigricans* and *C. longibracteata* are rare species in Kanagawa  
 220 prefecture. *Heterotropa muramatsui* (Makino) F. Maek. var. *tamaensis* (Makino) F.  
 221 Maek. also appear on the Red List (Kanagawa Prefectural Museum of Natural History  
 222 2006). Ecological studies of these species are currently in process.

223

## 224 **(2) Number of annual rings of three representative species**

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

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

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

251

## 252 **2. Changes of total NT, BA, and number of living, dead, or fallen trunks six years** 253 **after resumption of traditional management in abandoned substitution forest**

254

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

256 As shown Fig. 7, on the control plot in 2010, the total NT was 1,000 trunks/ha at 1.3 m  
 257 height (1.3H) and 700 trunks/ha at ground level (GL). By 2016, the numbers decreased  
 258 to 800 trunks/ha and 600 trunks/ha, respectively. The total NT at GL changed only  
 259 slightly from 2013 to 2016 on the control plots. On the mowing plots, many trees were  
 260 dead or fallen one year after cutting *P. chino*, the climbing plants, and the shade plants.  
 261 Starting in 2011, NT decreased gradually for the next five years. In 2010, NT was 900  
 262 trunks/ha at 1.3H and 550 trunks/ha at GL. By 2016, NT decreased to 600 trunks/ha  
 263 (1.3H) and 400 trunks/ha (GL). The ideal NT was reported by Shigematsu in the text  
 264 edited by Sigematsu (1987) when they proposed that 600-800 trunks/ha in the ideal  
 265 trunk density for Satoyama woods. It is difficult to judge the ideal NT, since the data are  
 266 differ with geographical condition, climate zone or tree age. However, we think the 600  
 267 trunks/ha (1.3H) and 400 trunks/ha (GL) are appropriate in this area.

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

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

278

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

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

286 The number of dead trunks in total on the mown plots was higher than that on the  
 287 control plots except for *Z. serrata* and *K. pictus* (middle graph in Fig. 9). The  
 288 proportions of the total number of dead trunks for each species on the mown plot over  
 289 the six years were: *Q. serrata*, and *S. japonicum*, 30%; *Q. acutissima*, *P. grayana* and *P.*  
 290 *jamasakura*, 40%; *F. lanuginosa* f. *serrata*, 50%; *S. japonica*, 70%; and *A. japonica*,  
 291 100%. Almost no *C. tschonoskii* were found dead on the control plot, but 20% of them  
 292 were dead on the mown plot. These results showed that subtle changes in moisture  
 293 content after cutting *P. chino*, shade plants, and climbing plants affected the growth of  
 294 the trees in this forest.

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

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

302

303 **Conclusion**

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

311 if it is considered desirable to maintain the traditional ecologies and values of the  
 312 Satoyama woods.

313

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 322 Hill Green Consortium in Kawasaki”, which is the output of a collaboration between the  
 323 Greenery Development Department, Construction and Greenery Development Bureau,  
 324 Kawasaki city office in Kanagawa Prefecture and Tokyo University of Agriculture in  
 325 2010.

326

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389 Figure and Appendix legends

390 Fig. 1 Study area (black square)

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

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

395 Fig. 4 Total number of trunks (NT) at 1.3 m height (white bar), and at ground level  
396 (black bar) on cutting/mown plot, and BA (basal area, m<sup>2</sup>/ha, dotted line) in 2010,  
397 just after cutting *Pleioblastus chino*, shade plants, climbing plants, etc. Total NT \* at  
398 1.3 m height and at \*\* ground level for *Quercus serrata*. #: evergreen conifer;  
399 parentheses: evergreen broad leaf; no symbol: temperate deciduous tree

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

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

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

411 Fig. 8 Changes in basal area (BA) (m<sup>2</sup>/ha), Upper area: control plot; Lower area: mown  
412 plot.

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

416 Fig. 9 Proportion of dead trees. x-axis: year; y-axis: relative numbers of dead trees (1.0  
417 NT) as of 2010. Values at bottom represent dead tree counts between 2010 and 2016  
418 on control plots (line) and on mown plots (dotted line). All tree species were present  
419 on both control and mown plots except for *Alnus japonica* and *Sapium japonicum*.  
420 Numbers in parentheses after botanical names indicate total number of samples. \*  
421 *Abies firma* (1 and 6); *Quercus myrsinaefolia* (19 and 5) on control and mown plots,

422 respectively; *Quercus acutissima* (8) on control plot. \*\* *Prunus grayana* (2); *Prunus*  
423 *jamasakura* (2); *Cornus controversa* (1) on control plot, and *Kalopanax pictus* (3) on  
424 mown plots. \*\*\*16% trunks were dead by fallen at root base

425

426

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

430

431 Many seedlings of all plant species were present besides those that were cut down.

432 For *Quercus serrata*, 189 dead trunks were felled. -: no data. \*H= height.