Causal analysis of the invasion of broad-leaved forest by bamboo in Japan

Okutomi, Kiyoshi, Shinoda, Shigeyuki & Fukuda, Hiroko

Vegetation Management Laboratory, Faculty of Agriculture, Tokyo University of Agriculture and Technology, Fuchu, Tokyo 183, Japan; Fax +81 423 675741

Abstract. In southwestern Tokyo the area covered by bamboo forest has expanded by a factor of 2.7 over the last 26 years. This has mainly been due to bamboo (*Phyllostachys pubescens*) invading secondary broad-leaved forests, probably after these were abandoned. In the first stage, bamboo sprouts develop from rhizomes at the periphery of the broad-leaved forest and then grow very quickly into young culms. In the next phase culm density increases annually, while the existing broad-leaved trees gradually lose their vitality and die. Finally, the broad-leaved forest is completely replaced by bamboo forest. The competitive ability of bamboo, based on its morphological and growth features, is suggested as the causal factor for the invasion: (1) bamboo can invade a neighboring broad-leaved forest by its vigorous rhizomes; (2) young bamboo culms can break through the canopy of broad-leaved trees; (3) bamboo quickly forms a crown in or above the canopy of the broad-leaved forest; (4) bamboo is very tolerant of strong wind and heavy snow accumulation; (5) bamboo culms, being very pliable during strong wind mechanically damage neighbouring broad-leaved trees.

Keywords: Bamboo forest expansion; Competitive ability; Culm density; Growth rate; *Phyllostachys pubescens*.

Introduction

Bamboo forest is one of the forest communities characterizing the natural landscape of hilly areas in various areas of present-day Japan, except in the north. Of the several kinds of bamboo forest, *Phyllostachys bambusoides*-dominated and *P. pubescens*-dominated forest cover large areas. The latter species was introduced in 1736 from China into the Japanese mainland (Kyushu) through the Ryukyu Islands (Ogura 1988). Bamboo was originally planted around farm houses and on the neighbouring hills, as a source of culms and sprouts. Until recently, bamboo forest was mainly restricted to such locations, except in parts of western Japan where large centres were established for the production of bamboo sprouts (used for food).

Massive expansion of bamboo forest, especially *P. pubescens* forest, has been observed recently in various parts of Japan. This has been so severe that the original natural landscape of hills has changed in places. Ogura (1981, 1988) reported the expansion of bamboo forest in the suburbs of Kyoto, a large production center for bamboo sprouts, but there are no reports from other areas of bamboo forest. The mechanism of the expansion of bamboo forest has apparently not been investigated.

In this study, emphasis was placed on investigating the actual conditions of bamboo forest expansion and on clarifying the mechanism of the invasion of secondary broad-leaved forest (former farm woodland and fuelwood forest) by bamboo, especially *P. pubescens*.

Methods

Survey of bamboo forest expansion

Bamboo forest expansion was investigated for the period 1961 to 1987 in the southwestern part of Tokyo (3423 ha). The areal change of bamboo forest was examined by comparing three maps (1:2500) showing bamboo forest distribution. These maps refer to a field survey made in 1987 and two aerial photographs taken in 1961 and 1974, respectively.

Analysis of broad-leaved forest invasion mechanism by bamboo

The mechanisms of bamboo invasion were analyzed in two different cases: (1) invasion of deciduous broad-leaved forest by *Phyllostachys pubescens* in the Tokyo Akikawa area, eastern Japan, and (2) invasion of evergreen broad-leaved forest by the same species in Fukuoka Kokura, southwestern Japan. Field data were collected in 1988 and 1989 from contiguous 15 m × 5 m plots in 15 m-wide belt-transects of 30 m or 25 m length, which were laid out in adjoining parts of bamboo forest bordering broad-leaved forest. For each tree with a height ≥ 5 m or a DBH ≥ 5 cm we recorded: species, location, height, crown height, DBH (or base diameter of stem-decayed wood), vitality (alive or dead) and, for bamboo, age class 1-yr, 2-yr or ≥ 3 yr old.
Results

Expansion of bamboo forest

The actual areas of bamboo forest in southwestern Tokyo in 1974 and 1987 were 2.4 and 2.7 times of those in 1961, respectively (Fig. 1). The increase was initially rapid but slower later on.

The last 26 years represent a time when southwestern Tokyo became conspicuously urbanized. It is likely that bamboo forest was destroyed over a large area. Therefore, the change of assumed total area of bamboo forest, i.e. the sum of actual area and destroyed area, was inspected. The assumed total area of bamboo forest in 1974 and 1987 increased to 2.6 and 3.4 times the actual area in 1961 respectively, and the increase was almost linear (Fig. 1).

Plant communities invaded by bamboo

In the period 1961 to 1974, various forest types (comprising 49.7 ha in total) had been replaced by bamboo forest (Fig. 2). More than half of the change to bamboo forest was at the expense of deciduous broad-leaved forest, followed by uncultivated fields, various scrub types and other community types. From 1974 to 1987 the area (37.7 ha) which changed to bamboo forest decreased a little, but the distribution of former types was almost the same (Fig. 2).

The forest type invaded most extensively by bamboo was broad-leaved forest. Species composition and structure of the forest were not examined in detail, but it is expected that most of these forests were *Quercus serrata*-*Q. acutissima* and *Q. serrata*-*Castanea crenata* forests, both of which are typical secondary forest communities in the area. In southwestern Japan, including another study area in Fukuoka Kokura, it is estimated that the plant community which was most often invaded most by bamboo was secondary evergreen broad-leaved forest dominated by *Castanopsis cuspidata var. sieboldii*. 

![Fig. 2. Percentage area of plant community types which changed to bamboo forest in the periods from 1961 to 1974 (left) and from 1974 to 1987 (right), in the survey area in southwestern Tokyo. Figures in brackets represent the total areas of the types which changed during each period, and the size of the circle graphs is proportional to the area.](image-url)
The mean speed of invasion of other plant community types by bamboo (i.e. the forward speed of the bamboo forest front), which was obtained by comparing the three maps, was approximately 3.0 m/yr in scrub, 2.5 m/yr in uncultivated fields and 1.8 m/yr in deciduous broad-leaved forest.

**Distribution and population structure of trees and bamboo**

The distribution and population structure of broad-leaved trees (deciduous in Akikawa, evergreen in Kokura) and bamboo in broad-leaved forest, broad-leaved-bamboo mixed forest and adjacent bamboo forest can be described as follows (Figs. 3-5):

1. Tree stems were abundant in the broad-leaved forest and among them only a few dead stems were found. Culms of *Phyllostachys pubescens* generally did not occur, and if they occurred, were only 1 yr old.

2. Stems of broad-leaved trees were also abundant in the broad-leaved-bamboo mixed forest, but the proportion of dead tree stems was higher. Culms of *P. pubescens* were also generally abundant, and the culm population was composed of every age class.

3. In the bamboo forest, tree stems were few and most of them were blighted and decayed. Culms of *P. pubescens* were distributed densely. Most culms were > 3 yr old. Few dead culms were found in the forest.

**Canopy structure**

In the broad-leaved forest, the canopy consisted mostly of broad-leaved tree foliage because *P. pubescens* culms were not abundant (Fig. 6). In the broad-leaved-bamboo mixed forest, the foliage of broad-leaved trees and that of *P. pubescens* were competing in the mid-canopy (Fig. 6). In the bamboo forest, the foliage of *P. pubescens* occupied the mid-canopy almost completely, while that of broad-leaved trees was less (Fig. 6). Tree foliage survived only on trees emerging above the bamboo foliage layer.

**Discussion**

**Cause of broad-leaved forest invasion by bamboo**

It is clear, that in centres of commercial bamboo-sprout production, the recent massive expansion of bamboo forest was the result of bamboo planting. In many other areas, including the present survey area, however, it is difficult to imagine that the large-scale expansion of

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**Fig. 3.** Distribution of tree stems (upper) and bamboo (*Phyllostachys pubescens*) culms (lower) in each plot of the belt transect in Tokyo Akikawa. Tree stems were classified by vitality (alive or dead) and DBH (the largest circle: ≥ 20 cm, the second: 15 - 20 cm, the third: 10 - 15 cm, the smallest: 5 - 10 cm) and bamboo culms by vitality and age.
bamboo forest was artificial, because these areas were not production centers for bamboo. From the results of the present investigation it is clear that the prime cause was direct invasion of broad-leaved forest by bamboo. The question arises, however, why the invasion has become so much more pronounced recently.

One answer may be the abandonment of broad-leaved forest adjacent to bamboo forest. Most of the broad-leaved forests adjacent to bamboo forest had been managed intensively for a long time as farm woodland or fuelwood forest. Under this management, various measures such as annual sprout cutting were taken to prevent bamboo invasion into broad-leaved forest. Since the latter half of the 1960s most of the broad-leaved forests of the area have been abandoned as sources of organic fertilizer and fuelwood. Consequently, bamboo was able to invade the adjacent broad-leaved forest.

**Mechanism of broad-leaved forest invasion by bamboo**

From the facts described above it is possible to say that *P. pubescens* invaded broad-leaved forest through a process depicted by the plot series from left to right in Figs. 3 to 6. The following steps can be identified in this invasion process: 1. Initially a few *P. pubescens* sprouts develop from the rhizomes which have already invaded the broad-leaved forest, and these grow so quickly into young culms that the distributional front of *P. pubescens* soon forms within the broad-leaved forest. 2. *P. pubescens* plants inside the broad-leaved forest increase their culms and foliage yearly and as a result, the surrounding broad-leaved trees lose their vitality and finally die. The forest community then becomes a mixed forest of broad-leaved trees and bamboo. 3. Culms of *P. pubescens* annually increase in number, while the living broad-leaved trees which have survived so far, gradually decrease. Only a few living broad-leaved trees remain, with their crowns overtopping the foliage layer of *P. pubescens* and decayed trees. 4. Finally, broad-leaved forest is completely replaced by *P. pubescens* forest. 5. Although dead culms of *P. pubescens* are found in the new *P. pubescens* forest, the bamboo forest may regenerate and maintain itself, because new culms develop yearly in the forest.

**Causal factors of broad-leaved forest invasion by bamboo**

How can bamboo forest win the competition with broad-leaved forest? A complete answer has not been presented yet, but the high competitive ability of bamboos such as *P. pubescens*, relating to their morphological structure (Ellenberg 1956), including growth, is pointed out as the causal factor. The significant characters are as follows:

1. Bamboo can invade neighboring forest by vigorous rhizomes.
2. Young bamboo culms can break through the canopy of broad-leaved forest easily and rapidly. Bamboo sprouts can appear from underground and grow to near maturity within only 2 to 3 months (Ueda 1979). The young culm, with its pointed head, grows directly upward to near its height growth limit without development of branches and leaves. When bamboo invades other forests, the young culms can grow rapidly into or even above the forest canopy.
3. Bamboo forms its crown in or above the canopy of broad-leaved forest in a short period. Bamboo develops almost all of its branches and leaves within 2 to 3 months. Therefore, in a very short period bamboo can form a mature crown in or above the canopy of the forest which it invaded, and this bamboo crown suppresses the saplings and seedlings of broad-leaved trees.
4. Bamboo has great tolerance of strong winds and heavy snow accumulation. Being elastic and very pliable, the culms and branches of bamboo are not
broken easily, even by strong winds such as typhoons or by heavy snowfall. Trees are damaged much more by such weather conditions.

5. Because bamboo culms are very pliable during strong winds, they cause mechanical damage to neighboring trees by breaking branches and leaves, except when the trees are much taller than bamboo. If this process is repeated frequently, the trees gradually decline and die.

![Fig. 5. Histograms of the number of tree stems, classified by vitality and evergreenness, and bamboo (Phyllostachys pubescens) culms, by vitality and age, in each plot of the belt transect in Tokyo Akikawa (left) and Fukuoka Kokura (right). Plot numbers are the same as in Figs. 3 and 4 respectively.](image1)

![Fig. 6. Canopy structure in each plot of the belt transect in Tokyo Akikawa, showing vertical distribution of tree stems and bamboo (Phyllostachys pubescens) culms with foliage. Plot numbers are the same as in Fig. 3.](image2)
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References


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