Growth failure and wild animal activity in a moso bamboo *Phyllostachys edulis* stand in Kyoto, western Japan

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Abstract: I evaluated moso bamboo *Phyllostachys edulis* growth and wild animal activity in a bamboo stand in Kyoto, western Japan, during 2016-2019. The aboveground biomass increment of the moso bamboo stand, an index of bamboo growth, was consistently negative throughout the study period, presumably due to limitations on the production of new bamboo shoots. Using camera traps, I frequently observed damages to moso bamboo shoots by wild boar *Sus scrofa* and sika deer *Cervus nippon* between March and May, which led to growth failure for new bamboo shoot production. This report highlights the possibility that wild animal activity may inhibit moso bamboo growth in naturalized moso bamboo stands in Japan.

Key Words: Bamboo invasion, Camera trap, *Cervus nippon*, *Phyllostachys pubescens*, *Sus scrofa*

Introduction

Bamboos, including the giant bamboo, moso bamboo *Phyllostachys edulis* (syn: *P. pubescens*), were historically managed by local peoples as a food resource and tools in Japan. However, as demand for bamboo has declined, managed bamboo stands have been abandoned and naturalized stands have successfully expanded throughout Japan’s satoyama landscapes over the past few decades (e.g., Okutomi et al. 1996; Shinohara et al. 2014; Suzuki 2015; Takano et al. 2017). This expansion is likely to continue because moso bamboo displays vigorous clonality via rhizomes (Isagi and Torii 1998). Although vigorous bamboo stands are often observed around Kyoto area, western Japan, I observed some stands exhibit growth failure (i.e., standing biomass of bamboo stands is decreasing), despite suitable abiotic conditions. In these stands, bamboo organs including new shoots and rhizomes are extensively damaged by wild animals (Fig.1b-e); individuals such as wild boar *Sus scrofa* could have considerable negative impacts on moso bamboo growth. Wild boars utilize bamboo stands and eat new bamboo shoots (e.g., Kodera et al. 2013; Ando 2015) and have been empirically known to negatively affect bamboo growth. However, basic descriptive studies on moso bamboo growth and damages by wild animals within the same stand remain limited. Here, I report on bamboo growth and wild animal activity using camera trap data from a naturalized bamboo stand.

Materials and Methods

1. Study site

This study was conducted in a moso bamboo stand in Kyoto, western Japan (34° 48’ N, 135° 49’ E, 220m in elevation) (Fig.1a). The study site was located on gentle (20° on average) west-facing slope. Mean annual air temperature and precipitation were 15.8°C and 1,581mm, respectively, over the study period (2016-2019), according to the closest meteorological station, located 5km from the study site (Kyotanabe, Japan Meteorological Agency 2020). Moso bamboo stand in this site was abandoned and was expanding into the adjacent secondary forest, which is dominated by *Quercus serrata*, *Pinus densiflora*, and *Ilex pedunculosa*, at a rate of 1.6-2.3m·year⁻¹, based on time-series aerial data from the past few decades (Kobayashi et al. 2018). After research in this stand started in 2016, I consistently observed the growth failure of moso bamboo shoots. Soil disturbance, exposed bamboo roots, and scattered young rhizomes and shoots were often visible on the forest floor (Fig.1b-e), implying that the recent growth failure might be related to heavy browsing by wild animals.
all moso bamboo ramets were recorded in September 2016 and December 2019. In May 2018, status of all newly emerged shoots (alive or dead) were recorded. The biomass of each ramet was estimated from its DBH using allometric equations, with separate consideration for ramet age classes and different organs, as described in previous studies (Isagi et al. 1997; Fukushima et al. 2015):

$$W = \sum W_i = \sum \alpha_i \cdot \text{DBH}^{\beta_i}$$ (1)

where $W$ is aboveground biomass (dry mass) of each ramet, $W_i$ is biomass of each aboveground organ (culm, branches, and leaves), and $\alpha$ and $\beta$ are constants taken from Abe and Shibata (2009) (see Table 1). Within each subplot, the total biomass of all living ramets (AGB, t·ha$^{-1}$), newly produced biomass originating from new ramets ($W_{\text{new}},$ t·ha$^{-1}$·year$^{-1}$), and newly dead biomass originating from dead ramets ($W_{\text{dead}},$ t·ha$^{-1}$·year$^{-1}$) was calculated from 2017 to 2019. The biomass increment ($\Delta G$) of each subplot, an index of bamboo growth, was then calculated using the following equation:

$$\Delta G = W_{\text{new}} - W_{\text{dead}}$$ (2)

3. Camera trap surveys

A single year of camera trapping was used to evaluate behaviors of wild animals in the study plot (February 2019-January 2020) (Figs. 2, 3). Three infrared motion-detecting camera traps were deployed (H65 TRAIL CAMERA, Apeman International Co., Ltd., Hong Kong) at a height of ca. 150cm on trees or bamboos near animal
Table 1. Coefficients of allometric equations ($W=\alpha DBH^\beta$) that were used to estimate biomasses (dry mass, $W$) of organs from the culm diameters at breast height (DBH) in moso bamboo *Phyllostachys edulis*, as reported by Abe and Shibata (2009) in Kyoto, western Japan.

| Organ | Ramet age class | $\alpha$ | $\beta$ | N | $r^2$ |
|-------|-----------------|----------|--------|---|------|
| Leaves | current-year | 1.149×10^{-2} | 1.515 | 7 | 0.853 |
|       | >one-year | 4.774×10^{-3} | 1.976 | 8 | 0.851 |
| Branches | current-year | 1.045×10^{-1} | 1.185 | 7 | 0.722 |
|        | >one-year | 4.647×10^{-2} | 1.483 | 8 | 0.740 |
| Culms  | current-year | 6.210×10^{-2} | 2.261 | 7 | 0.951 |
|        | >one-year | 1.305×10^{-1} | 2.052 | 8 | 0.915 |

Fig. 3. Images of wild boar (a and b) and sika deer (c and d) obtained from camera traps placed in the study site in Kyoto, western Japan. Panels (b and d) show browsing activity on young, recently emerged bamboo shoots.

trails within and between the two transects (Fig.2). The shooting range of the camera traps was ca. 4×15 m². Cameras were set to record 10-s videos upon triggering. Data were downloaded from cameras once every two months; times of observation and numbers of individuals captured were recorded. Most captures were of wild boar and sika deer, with a minority “other” category recorded. Each observation was given an activity code of “yes” or “no”, where “yes” denoted observation of activities that were damaging to moso bamboo (i.e., digging and browsing bamboo organs). The same individuals were sometimes captured on successive videos as the shooting interval time on the cameras was set to 0s. These duplicate individuals were removed from further analyses. Monthly capture frequencies of wild boar, sika deer, and other wild animals were then calculated.

Results

I. Moso bamboo growth

Growth parameters within the two transect plots over the study period are shown in Table 2. In 2016, living ramet density and AGB tended to decrease with an increase in subplot identity, i.e., both parameters decreased from the pure bamboo area toward stand edge. However, this pattern was not observed in $W_{\text{new}}$ or $W_{\text{dead}}$. Mean $W_{\text{new}}$ was 6-fold and 11-fold lower than mean $W_{\text{dead}}$ within transects 1 and 2, respectively. The ratio of newly produced biomass ($W_{\text{new}}$) to total living biomass (AGB) was 0.2%.

Δ$G$ was negative in all subplots over the three-year study period (-3.6-0.6 ton·ha⁻¹·year⁻¹, see Δ$G$ values in Table 2).

2. Wild animal activity

The total capture frequency of all wild animals within the surveyed year was 213.7 ± 11.5 year⁻¹ (mean ± S.D., n=3). Wild boar and sika deer constituted 87% of the total (100.0 ± 22.0 year⁻¹ for wild boar and 85.0 ± 8.2 year⁻¹ for sika deer). These two wild animals were typically
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Table 2. Living ramet density and aboveground biomass (AGB) of studied moso bamboo stand in Kyoto, western Japan in September 2016 and newly produced biomass ($W_{new}$), dead biomass ($W_{dead}$), and biomass increment ($\Delta G$) of the stand over a three-year period (2017-2019).

| Subplot ID | Ramet density $10^{5}$m$^{-2}$ | AGB t·ha$^{-1}$ | $W_{new}$ t·ha$^{-1}$·year$^{-1}$ | $W_{dead}$ t·ha$^{-1}$·year$^{-1}$ | $\Delta G$ t·ha$^{-1}$·year$^{-1}$ |
|------------|-------------------------------|-----------------|-------------------------------|-------------------------------|-----------------------------|
| Transect 1  | 24                            | 26              | 110.6                        | 2.5                           | 0                           | -3.6                        |
| Transect 2  | 14                            | 19              | 73.3                         | 0                             | 1.2                         | -1.1                        |
| Transect 3  | 8                             | 14              | 43.5                         | 0                             | 2.8                         | -2.4                        |
| Transect 4  | 6                             | 9               | 29.6                         | 0                             | 3.2                         | -3.6                        |
| Transect 5  | 1                             | 5               | 2.2                          | 0                             | 0                           | 0                           |
| Transect 6  | 1                             | 6               | 3.2                          | 0                             | 0                           | 0                           |
| Transect 7  | 1                             | 6               | 3.2                          | 0                             | 0                           | 0                           |
| Transect 8  | 1                             | 7               | 24.3                         | 3.6                           | 1.1                         | -1.2                        |
| Transect 9  | 1                             | 9               | 20.6                         | 1.0                           | 0                           | 0                           |
| Transect 10 | 2                             | 2               | 1.1                          | 0.1                           | 0                           | 0                           |

mean ± S.D. 9.4 ± 8.1 10.4 ± 8.0 39.4 ± 37.3 38.6 ± 35.3 0.4 ± 0.9 0.1 ± 0.1 1.8 ± 1.4 1.1 ± 1.2 -1.4 ± 1.5 -1.0 ± 1.2

Fig. 4. Monthly capture frequencies of a) wild boar and b) sika deer from February 2019 to January 2020 in the study site in Kyoto, western Japan. In each panel, "yes" denotes observed behaviors that may affect moso bamboo growth. Mean values are shown ($n=3$).

Discussion

I demonstrated that $\Delta G$ was negative over a three-year period in both transects (Table 2). The observed ratios of newly produced biomass to total living biomass (0-2%) were much lower than previously reported values (e.g., 18.1t·ha$^{-1}$/137.9t·ha$^{-1}$=13%, Isagi et al. 1997) from the Kyoto area where no wild animal activities were recorded. This result suggests that the studied bamboo stand is failing to grow due to major limitations on the production of new bamboo shoots. I further showed that wild boar and sika deer were eating young bamboo organs, based on camera trap findings during February 2019-January 2020 and field observations (Figs.1, 3, 4), which implies that limitations on new bamboo shoots are due to heavy and frequent browsing by these wild animals. Wild boar, which often dug for belowground bamboo organs, appeared to congregate in the bamboo stand from March to May and in October (Figs.3a, b, 4a), when new shoots or rhizomes are produced (Ueda 1960). Sika deer, which typically browse young aboveground shoots, congregated from April to May (Figs.3c, d, 4b).

Relationships between moso bamboo and wild animals typically have been assessed from a viewpoint of wild animal management. Recent studies have shown that unmanaged bamboo stands provide important habitats for wild boars, particularly in spring (e.g., Kodera et al. 2013; Ando 2015). However, moso bamboo growth and wild animal activities were not previously assessed within the same stand. This study clearly demonstrated growth failure of new shoot production in a moso bamboo stand, presumably resulting from wild boar and sika deer activity. These results suggest that wild animal activity may inhibit vigorous moso bamboo growth. To understand long-term dynamics between naturalized moso bamboo growth and wild animal activity in satoyama landscapes, more detailed observations and assessments are needed.
Acknowledgements

I extend my thanks to the Forestry and Forest Products Research Institute for their permission to use their land. My supervisors, Dr. Kitayama K., Dr. Onoda Y. and Dr. Osawa N., provided insightful comments and guidance for this study and for this manuscript. I also thank the members of the Laboratory of Forest Ecology, Kyoto University for their assistance with fieldwork. Ando S. provided comments regarding wild animal behavior in bamboo stands. This work was supported by a Sasagawa Scientific Research Grant from The Japan Science Society (No. 2018-5001) and Grant-in Aid for JSPS fellows (No. 19J11336).

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