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RESEARCH ARTICLE

# Invasiveness of *Chimonobambusa quadrangularis* (Francheschi) Makino in a remnant secondary forest of Cibodas Botanic Gardens, Indonesia and its proposed management

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**Abstract**: *Chimonobambusa quadrangularis* is one of 75 invasive plant species in Indonesia and found in Cibodas Botanic Gardens forest, Mt. Gede Pangrango National Park forest, and Sibolangit Tourist Park. We attempt to assess the population, spread rate, and biomass of *C. quadrangularis* in the Wornojiwo forest and the correlation between the presence of *C. quadrangularis* in the garden and the existing plant population. Nine (10 meters wide) purposive sampling belt transect was placed to measure vegetation structure and composition. The results indicate that the forest structure (vis-a-vis tree diameter distribution and stratification) was changing, indicating that the Wornojiwo forest had been disturbed considerably. *C. quadrangularis* dominated the shrub life form with a total population of 3,488 individuals and an average density of 1.4 individuals.m$^{-2}$. The spread rate of *C. quadrangularis* was estimated at 422 m$^2$.year$^{-1}$ with a radial distribution pattern. The total biomass of *C. quadrangularis* was 12.66 Mg.ha$^{-1}$, and its population density has a weak negative correlation with species richness and abundance of tree, shrub, herb, and seedling species. Active management of this species is needed to restrict its invasion to the natural forest around Cibodas Botanic Gardens. The study indicates more rational forest management and minimizing human interventions if long-term conservation is to be achieved.

*Keywords: Chimonobambusa quadrangularis*, forest structure, invasive species, population assessment, tropical forest.

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## Introduction

*Chimonobambusa quadrangularis* (Francheschi) Makino (synonym: *Bambusa quadrangularis*, common name: Square Bamboo, local Sundanese name: *Awi Kirisi*) has its originates from China. This bamboo can be described as a bamboo with a maximum culm height that can reach up to 6 m, have attractive square stems, vertical dark green running culms with dense whorls of leaves at each node, and the ability to grow under the shade of the forest to form dense canopy reaching about 30-40 culms.m$^{-2}$ (Benzoa and Rauch, 1997; Tjitrosoedirdjo *et al*., 2016). Square bamboo is a significant bamboo species widely farmed in Southwest China. It is mainly used to produce edible shoots, considered nutritious and palatable (Chen *et al*., 2019).

This monopodial species is reported as invasive in Hawaii after introduction but is not considered invasive in Tanzania, Southeast Asia, Japan, New Zealand, the USA and parts of Europe, including the UK (Wahyuni and Tjitrosoedirdjo, 2013; Darmayanto and Muhaimin, 2017). *C. quadrangularis* is also

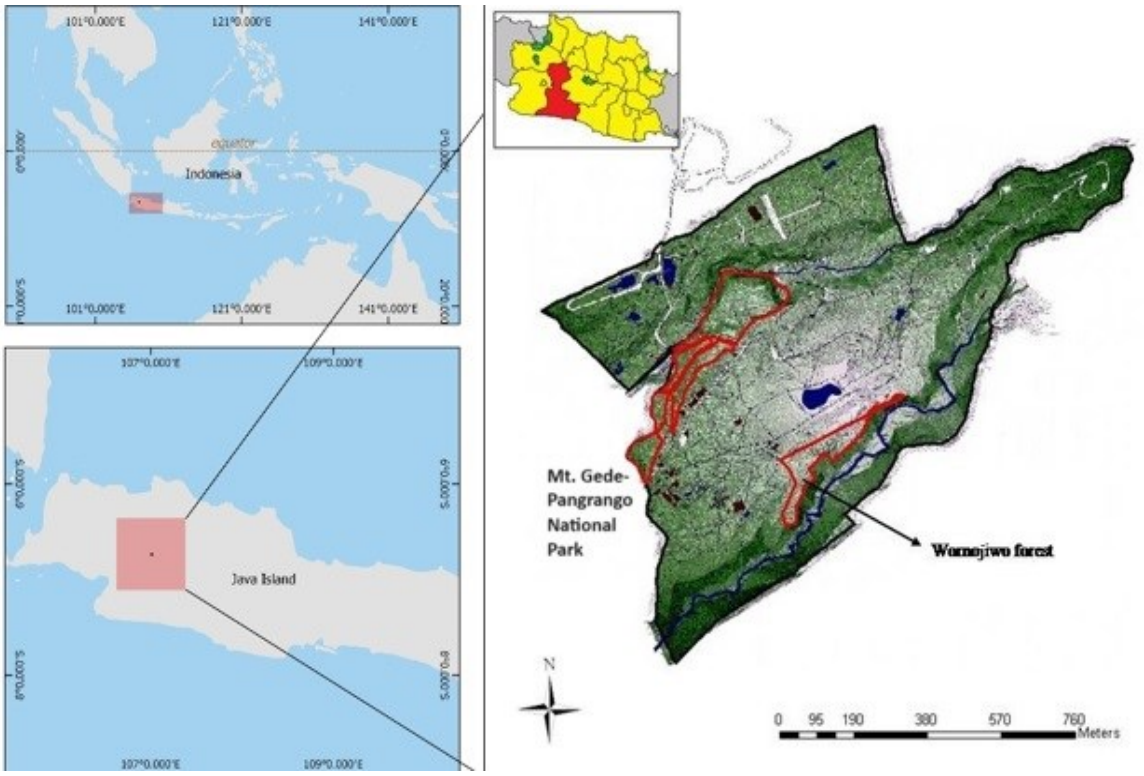



**Fig 1**. Map of study site

recorded as one of invasive bamboo in Indonesia, especially in Cibodas Botanic Gardens and Mt. Gede Pangrango National Park in Java and Sibolangit Tourist Park in Sumatera (Mutaqien *et al*., 2011; Zuhri and Mutaqien, 2013; Junaedi, 2014; Tjitrosoedirdjo *et al*., 2016; Damayanto and Muhaimin, 2017).

In Java, *C. quadrangularis* was determined as deliberately planted as a live fence in Cibodas Botanic Gardens and which then spread to an adjacent forest of Mt. Gede Pangrango National Park up to 50 meters from the boundary area (Zuhri *et al*., 2018). The population of *C. quadrangularis* in a remnant secondary forest of Cibodas Botanic Gardens was not reported. This paper aims to assess the invasiveness of *C. quadrangularis* by measuring its population, spread rate, and biomass in the remnant secondary forest and the correlation between the presence of *C. quadrangularis* in the national park to existing plant population in the botanical garden.

## Materials and Methods

### Study site

A study was conducted in the Wornojiwo forest, a 3.9 ha secondary remnant forest in Cibodas Botanic Gardens, Cianjur Regency, West Java, Indonesia (Fig 1). The data was collected through a vegetation survey using a nine-line transect of 10 m in width. Each transect was purposively located, allied with an existing permanent plot and divided into nested subplots sampling 10x10 m, 5x5 m, and 1x1 m for trees, shrubs, poles, small herbs and seedlings, respectively. The population of *C. quadrangularis* was enumerated and classified as young, old, mature and damaged/ died out. The result was compared with the presence of *C. quadrangularis* in 2010 (Mutaqien *et al*., 2011). Canopy openness and biomass were also measured for further analyses.

Plant community data were analyzed for dominance level using the importance value index (*IVI*), Shannon-Wienner diversity index (*H'*), and Shannon evenness index (*e*) (Shannon and Weaver, 1969; Curtis and McIntos, 1951; Pileou, 1966; Beals *et al.,* 2000; Mueller-Dombois and Ellenberg 2002). Species evenness ranges from zero to one, with zero signifying no evenness and one meaning complete evenness (Beals *et al*., 2000).

**Table 1**. Diversity, evenness and dominance of plant species in the study area.

| Habitus | Number of species | H' | E | Family | Top Dominance Level | IVI |
|---|---|---|---|---|---|---|
| Tree | 39 | 2.96 | 0.88 | Fagaceae | *Castanopsis argentea* | 66.81 |
| | | | | Euphorbiaceae | *Ostodes paniculata* | 32.43 |
| | | | | Urticaceae | *Oreochnide sylvatica* | 27.46 |
| | | | | Araliaceae | *Macropanax dispermus* | 27.03 |
| | | | | Altingiaceae | *Liquidambar excelsa* | 22.27 |
| Shrub | 80 | 2.43 | 0.56 | Poaceae | *Chimonobambusa quadrangularis** | 106.40 |
| | | | | Solanaceae | *Cestrum aurantiacum** | 16.10 |
| | | | | Acanthaceae | *Strobilanthes laevigata* | 12.54 |
| | | | | Euphorbiaceae | *Ostodes paniculata* | 11.85 |
| | | | | Annonaceae | *Polyalthia subcordata* | 10.44 |
| Herb | 84 | 2.95 | 0.67 | Urticaceae | *Elatostema* sp. | 26.41 |
| | | | | Acanthaceae | *Strobilanthes laevigata* | 16.15 |
| | | | | Marantaceae | *Geoppertia lietzei* | 7.46 |
| | | | | Araceae | *Schismatoglottis* sp. | 6.03 |
| | | | | Gesneriaceae | *Cyrtandra picta* Blume | 3.63 |
| Total | 203 | | | | | |

## Results

### *C. quadrangularis* population, spread rate, and biomass

A total of 3,488 culms of C. quadrangularis were found in the study area with an average density of 1.4 ± 0.59 culms.m$^2$ or 14,000 culms hectare$^1$. The importance value index of C. quadrangularis was 106.40, significantly higher than other species (Table 1).

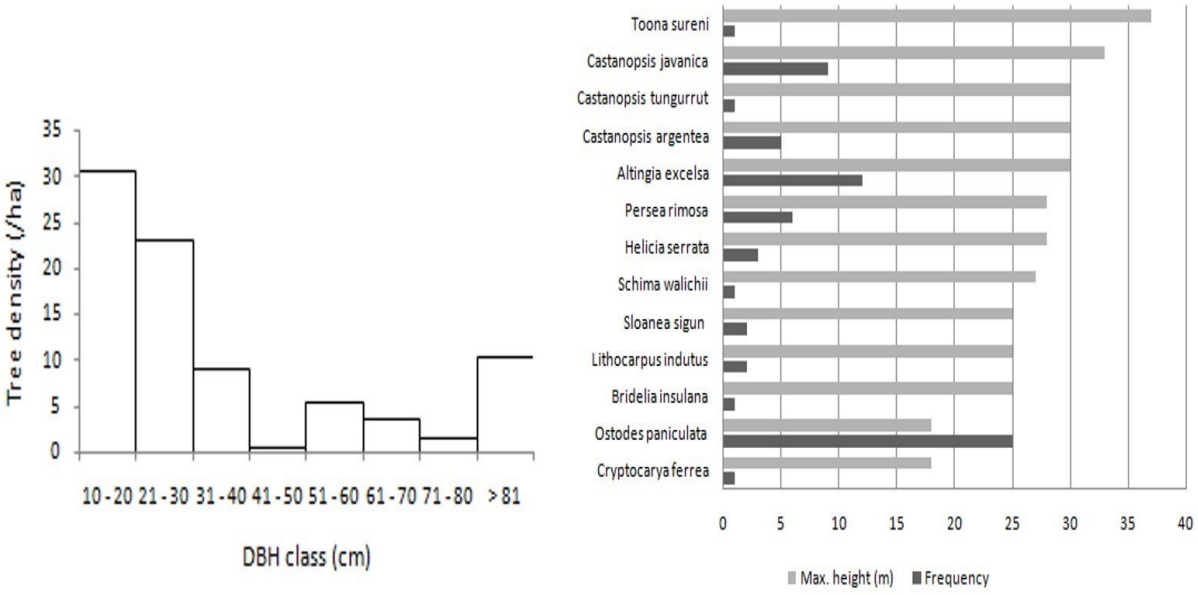



**Fig 2**. Tree diameter distribution (left) and forest stratification in the study area (right)

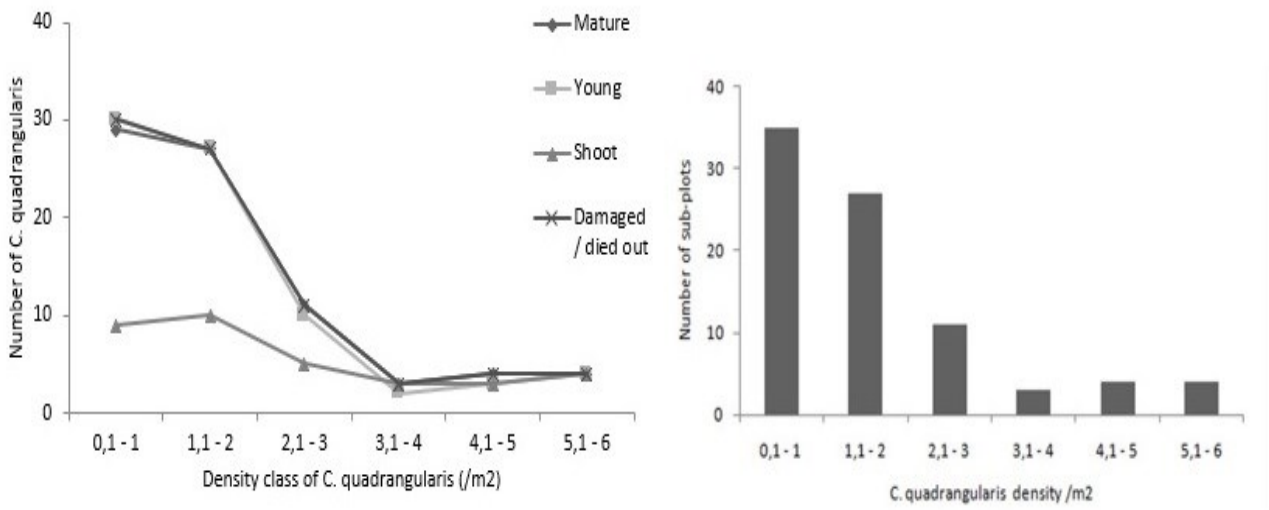



**Fig 3**. Number individual of *C. quadrangularis* from forest edge to interior forest (left) and the number of sub-plots in each *C. quadrangularis* class density (right)

The regeneration of *C. quadrangularis* can be identified in Fig 2. The shoot stage has a deficient number of individuals (46 individuals), followed by the young stage (322). On the other hand, the mature stage and damaged culms were significantly higher (1,528 and 1,592 numbers in total, respectively).

The number of sub-plots occupied by *C. quadrangularis* was not equal in each class density of *C. quadrangularis* (Fig 2). *C. quadrangularis* was mostly encountered in low density. The spread rate of *C. quadrangularis* can be seen from the schematic diagram in Fig 3.

The total above-ground biomass estimation of *C. quadrangularis* was 12.66 Mg.ha$^{-1}$. Stems, leaves, twigs, and litter contributed the highest biomass, 3.2 Mg.ha$^{-1}$, 1.4 Mg.ha$^{-1}$, 1.2 Mg.ha$^{-1}$, and 0.6 Mg.ha$^{-1,}$ respectively (Fig 4). This specific calculation would be necessary for managing this invasive species, for example, if we need to eradicate and utilize its biomass.

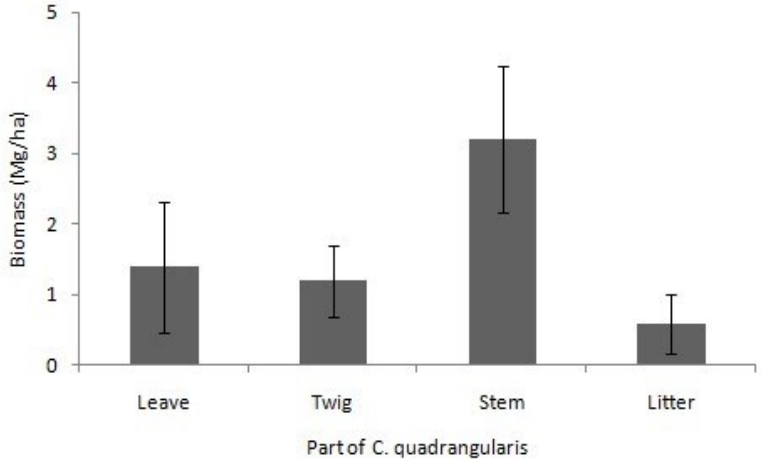



**Fig 4**. Above-ground biomass of *C. quadrangularis*

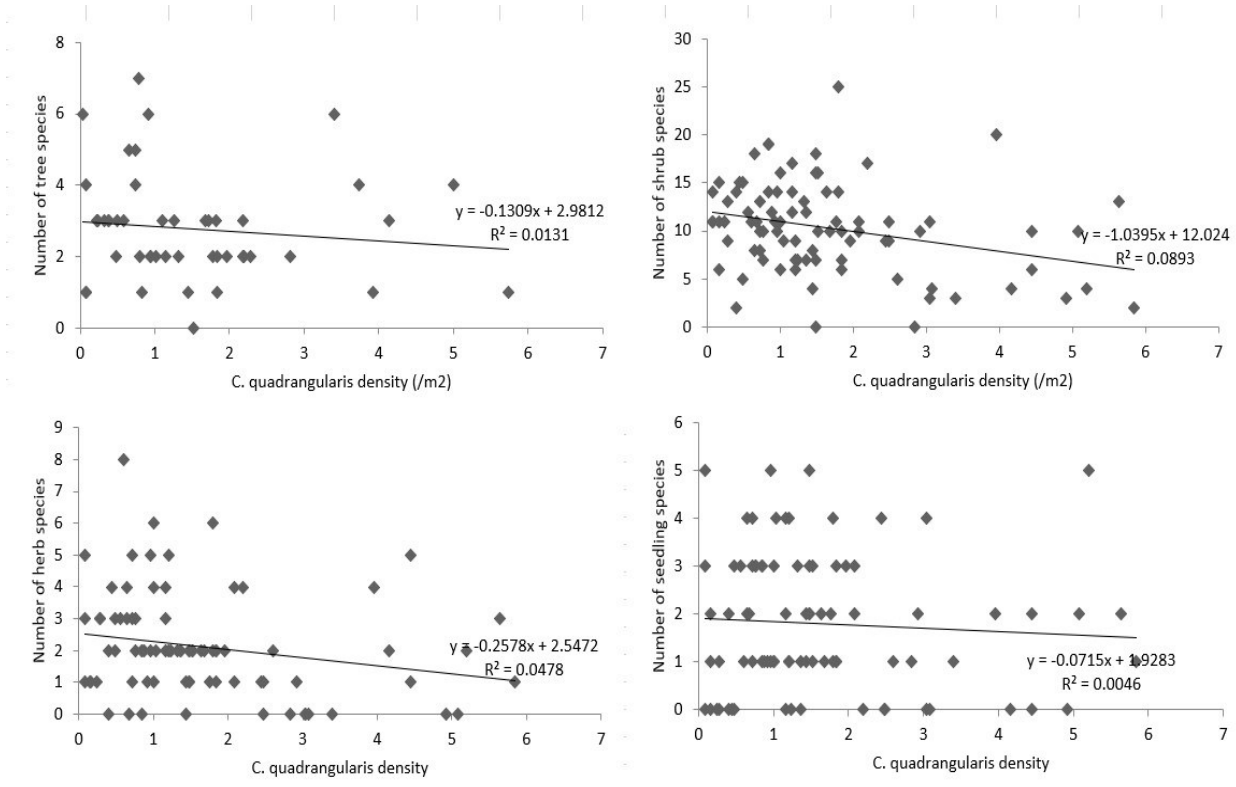



**Fig 5**. The relationship density class of *C. quadrangularis* on the number of (a) tree species (b) shrub species (c) herb species and (d) seedling species

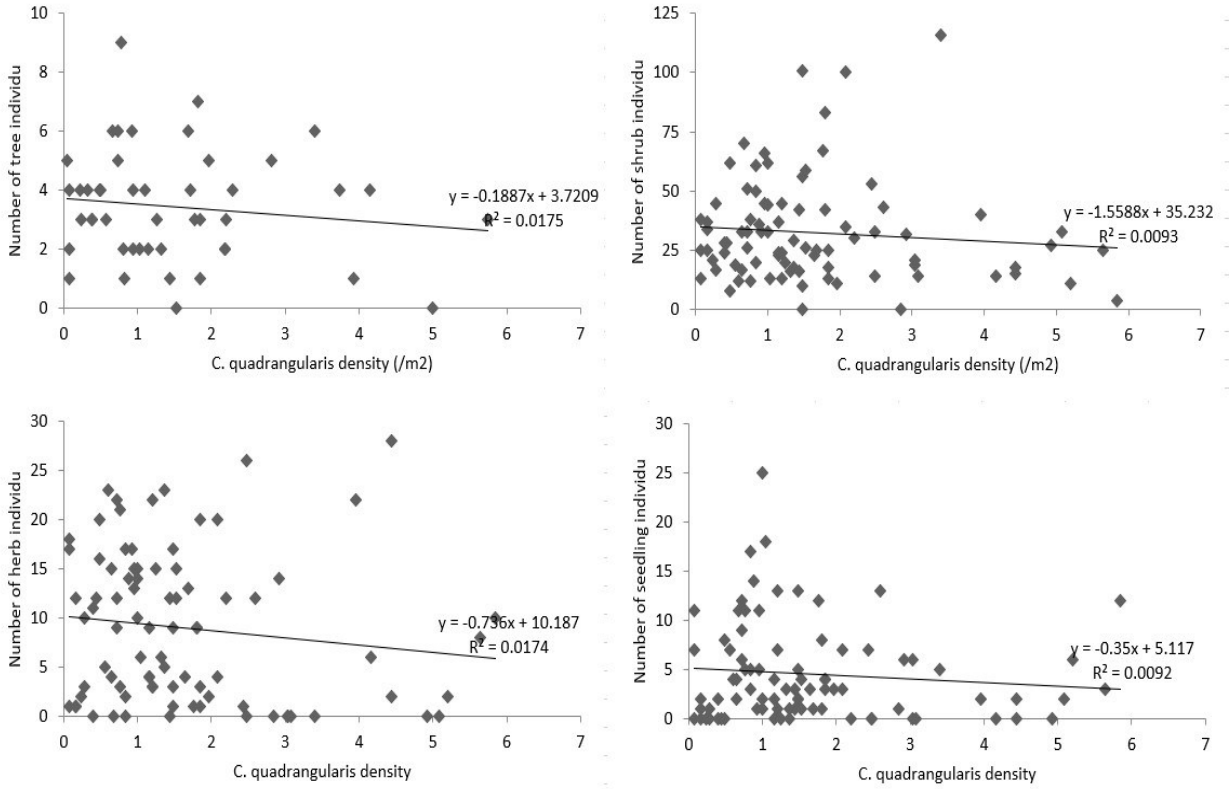
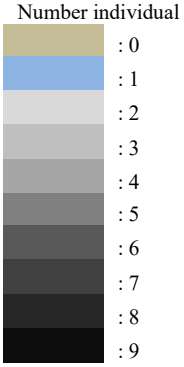



**Fig 6.** The relationship density class of *C. quadrangularis* on number of individual (a) tree (b) shrub (c) herb and (d) seedling

**Table 2**. Seedling species under *C. quadrangularis* stands

| Seedling species under *C. quadrangularis* stands | *C. quadrangularis* class density (/m$^2$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 0.1 - 1 | 1.1 – 2 | 2.1 – 3 | 3.1 - 4 | 4.1 - 5 | 5.1 - 6 |
| *Ficus ribes* Reinw. ex Blume (?) | 1 | 9 | 4 | 3 | 0 | 0 | 3 |
| *Strobilanthes laevigata* C.B.Clarke | 3 | 9 | 5 | 3 | 0 | 0 | 2 |
| *Ardisia fuliginosa* Blume | 2 | 2 | 1 | 1 | 0 | 0 | 1 |
| *Cestrum aurantiacum* Lindl. | 4 | 1 | 3 | 1 | 1 | 0 | 1 |
| *Cryptocarya ferrea* Blume | 0 | 0 | 1 | 1 | 1 | 0 | 1 |
| *Ostodes paniculata* Blume | 2 | 5 | 3 | 0 | 0 | 0 | 1 |
| *Pinanga coronate* (Blume) Blume | 1 | 3 | 2 | 0 | 1 | 1 | 1 |
| *Polyalthia subcordata* (Blume) Blume | 0 | 3 | 0 | 0 | 0 | 1 | 0 |
| *Pavetta montana* Reinw. ex Blume | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| *Calamus* sp. | 0 | 3 | 3 | 1 | 0 | 0 | 0 |
| *Helicia serrata* (R. Br.) Blume | 2 | 3 | 0 | 1 | 0 | 0 | 0 |
| *Lasianthus laevigatus* Blume | 2 | 3 | 3 | 1 | 0 | 0 | 0 |
| *Pittosporum* sp. | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| *Castanopsis argentea* (Blume) A.DC. | 0 | 1 | 2 | 0 | 0 | 0 | 0 |
| *Hydrangea febrifuga* (Lour.) Y.De Smet and Granados | 1 | 1 | 2 | 0 | 0 | 0 | 0 |
| *Ficus ampelos* Burm.f. | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| *Machilus rimosus* (Blume) Blume | 0 | 4 | 2 | 0 | 0 | 0 | 0 |
| *Eumachia montana* (Blume) I.M. Turner | 0 | 2 | 2 | 0 | 0 | 0 | 0 |
| *Acer laurinum* Hassk. | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| *Amorphophallus* sp. | 0 | 2 | 1 | 0 | 0 | 0 | 0 |
| *Cinnamomum* sp. | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| *Flacourtia* sp. | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| *Magnolia lilifera* (L.) Baill. | 0 | 2 | 1 | 0 | 0 | 0 | 0 |
| *Oreocnide sylvatica* (Blume) Miq. | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| *Pinanga javana* Blume | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| *Myrsine hasseltii* Blume ex Scheff. | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| *Saurauia cauliflora* DC | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| *Trevesia sundaica* Miq. | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| *Aglaia* sp. | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Coffea canephora* Pierre ex Froehner | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Sphaeropteris glauca* (Blume) R.M. Tryon | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Neolitsea* sp. | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Plectocomia elongate* Mart. ex Blume | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Polygala venenose* Juss. ex Poir. | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Rubia cordifolia* L. | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Litsea cordata* (Jack) Hook.f. | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Luvunga sarmentosa* (Blume) Kurz | 0 | 0 | 0 | 0 | 0 | 0 | 0 |




## Effect of *C. quadrangularis* on other plant life forms

The regression analysis results showed the density of *C. quadrangularis* has a negative linear correlation with species richness and abundance of the tree, shrub, herb, and seedling (Fig 5 and Fig 6). Thirty-seven seedlings of tree species existed under *C. quadrangularis* stands (Table 2).

## Discussion

### *C. quadrangularis* population, spread rate, and biomass

The population of *C. quadrangularis* was more abundant at the forest edge near the garden, then declined gradually towards the inside in all growth stages (Fig 2), within a maximum limit of 70 meters from its periphery.The population of *C. quadrangularis* in Wornojiwo Forest was twice as dense as compared to bamboo forests in Japan (Sharma, 1980; Wang and Stapleton, 2006). *C. quadrangularis* root system (stolon) spreads rapidly below ground and may grow laterally 1-2 meters (s) from the mother plants. When these underground culm portions with root (offset) are exposed from the ground, a square shoot will grow immediately with massive whorls of leaves at each node. However, *C. quadrangularis* in the Wornojiwo forest only reproduced vegetatively and was never found flowering. Based on Dutta and Devi (2013) and Tiwari *et al*., (2018), the regeneration of *C. quadrangularis* in Wornojiwo Forest during the study time (dry season) was catagorized closer to poor. Only young bamboo culms existed in minimal numbers compared to other stages. However, we firmly believe that the regeneration of this invasive species in the rainy season must be excellent.

A series of field mapping and aerial photos over successive years are the most accurate methods to study the spread of species (Hasting *et al*., 2005). Approximately 1,800 $m^2$ of area was occupied by this species in the permanent plot of the Wornojiwo forest in 2010 (Fig 7). Nine years later, this area expanded more than twice to about 4,900 $m^2$. Assuming the spread rate is a linear increase, it could be calculated that the area occupied by *C. quadrangularis* escalated ± 344 $m^2.year^{-1}$. Assuming the conditions are stable, it can be estimated that in 2046, *C. quadrangularis* would occupy all areas of the permanent plot in the Wornojiwo forest. Thus, it can be predicted that *C. quadrangularis* started its establishment at Wornojiwo forest in 2005.

A radial expansion pattern in *C. quadrangularis* was noticed in the permanent plot (Fig 7). As can be seen from the 2010 map, this species started growth from the center of the forest and then dispersed inside the forest and out to the garden area ranging from 10-40 meters linear over the previous sampling or 1-4 $m.y^{-1}$. The garden area is highly maintained and managed intensively; therefore, the spread rate in this area appears to be relatively slower (1-2 $m.y^{-1}$).

An alien plant species is considered invasive if it is vegetatively spread >2 $m.y^{-1}$ on average (Richardson *et al*. 2000), It is indicated that *C. quadrangularis* was invasive in the Wornojiwo forest. However, this result cannot be univocally compared to other organisms or sites if the primary population dynamics are poorly identified (Grosholz 1996, Mack and Lonsdale 2001).

The amount of total biomass of *C. quadrangularis*, i.e., 12.66 $Mg.ha^{-1}$, was similar to the shrub of tropical dry deciduous forest of Madhya Pradesh State of India, 12.67 $Mg.ha^{-1}$ (Salunkhe *et al*. 2014), but much lower than if forest stands still occupy the area. In the Wornojiwo forest, the biomass of tree stand (DBH > 10 cm) was about 860.82 $Mg.ha^{-1}$ in 2014 (Nasihin *et al*., 2015).

Generally, bamboo biomass was higher than other species of understorey biomass. Above-ground biomass of *Bambusa cacharensis, B. vulgaris*, *B. balcooa* and *Gigantochloa atter* were 15.36 $Mg.ha^{-1}$, 8.29 $Mg.ha^{-1}$, 9.33 $Mg.ha^{-1}$, and 73.55 $Mg.ha^{-1}$ respectively higher than the biomass of understorey on stands of Persian lilac (*Melia azedarach*), Mahogany (*Swietenia macrophylla*) and Teak (*Tectona grandis*), which was 6.15 $Mg.ha^{-1}$, 4.23 $Mg.ha^{-1}$, and 0.115 $Mg.ha^{-1}$ respectively (Nath *et al*., 2009, Sihaloho *et al*., 2016, Basrudin and Wahyuni 2017, Daud *et al*., 2018).

### Effect of *C. quadrangularis* on other plant life forms

The weak relationships of *C. quadrangularis* density with species richness and abundance of the tree, shrub, herb, and seedling suggested that the presence of *C. quadrangularis* did not influence the existing plant community in the disturbed forest ecosystem. Trees, shrubs, herbs, and seedlings species and individuals were concentrated at lower densities of *C. quadrangularis*. Possible causes of herb and shrub layer dynamics could be due to changes in the light regime resulting from changes in canopy structure, particularly gaps, changes in species composition and abundance of the canopy trees, and other environmental factors such as changes in fire frequency or human activities (Davison and Forman,1982).

Seven species seedlings survived under the various densities of *C. quadrangularis*, i.e., *Ficus* sp., *Strobilanthes laevigata* C.B.Clarke, *Ardisia fuliginosa* Blume, *Cestrum aurantiacum* Lindl., *Cryptocarya ferrea* Blume, *Ostodes paniculata* Blume, and *Pinanga*

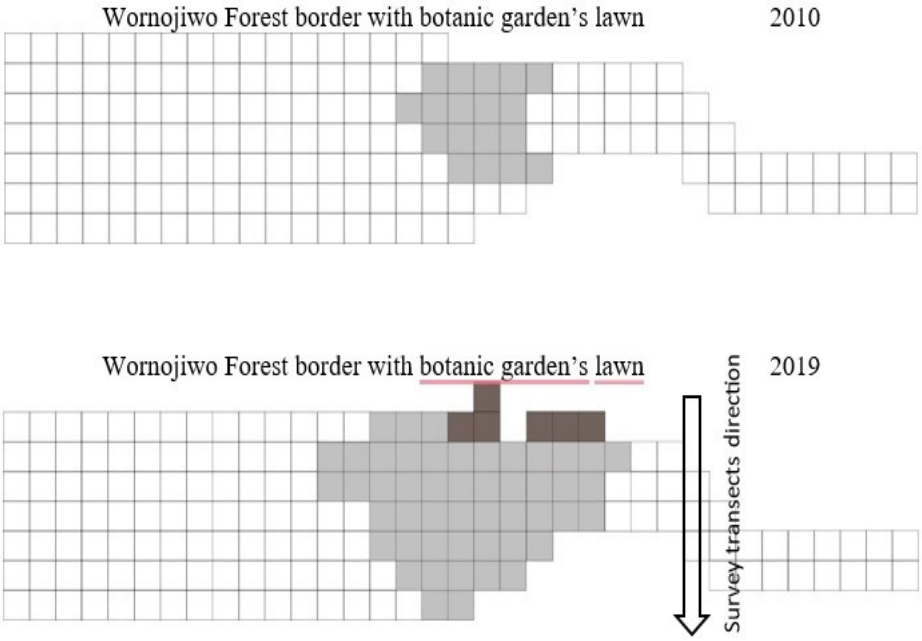



**Fig 7**. The spread of *C. quadrangularis* in plot permanent Wornojiwo forest in 2010 (upper) and 2019 (below). Dark shadow showed *C. quadrangularis* distribution outside the permanent plot.

*coronata* (Blume ex Mart.) Blume. However, some species were not found under the high density of *C. quadrangularis*. The shade of *C. quadrangularis* canopy possibly limited light penetration, even though a weak correlation was shown by *C. quadrangularis* density on canopy openness (Fig 8).

### *C. quadrangularis* management implications

*C. quadrangularis* was introduced to Cibodas Botanic Gardens around 1920 as *Phyllostachys quadrangularis* (Dakkus 1930, Nasution 1963, Widjaya 2001, Damayanto and Muhaimin 2017). Cibodas Botanic Gardens could succeed in managing the invasive bamboo by digging

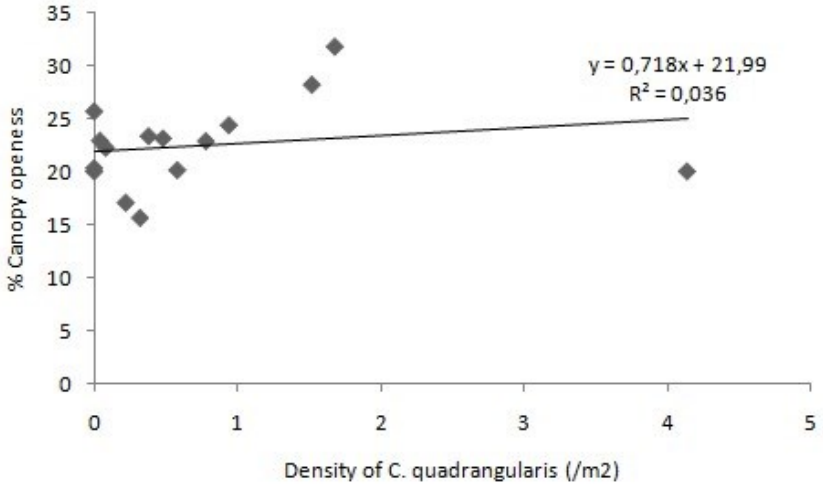



**Fig 8.** The relation of *C. quadrangularis* density on percent canopy openness

a trench around the bamboo collection and maintaining it without spreading it beyond. Whether the existence of *C. quadrangularis* noticed in Wornojiwo was intentional or unintentional through active human intervention is not clear.

However, it is recognized that proactive management interventions are needed to restrict its rapid spread to the natural forest around Cibodas Botanic Gardens. Even a single culm or offset potentially forms a patch of *C. quadrangularis,* extending to many meters. Therefore, it is crucial to prevent the expansion of *C. quadrangularis* and then physically eliminate it.

Wornojiwo forest is best described as a disturbed remnant forest. Wornojiwo forest is "a small island among the built-up habitats" in a fragile ecosystem separated from its primary habitat, Mt. Gede Pangrango National Park. Conservation of some small islands of biodiversity is essential to maintain genetic resources and as a habitat refuge for animals. We underline that vegetation restoration and prohibition of human activities in the Wornojiwo forest are highly required to ensure natural regeneration.

If properly utilised, the importance of *C. quadrangularis* biomass can increase their benefits to the local community. The shoots are edible after proper processing, and local communities usually harvest them during the rainy season when they are abundant. *C. quadrangularis* shoots are nutritionally rich, with protein, fat, carbohydrate, cellulose, vitamin C, vitamin B, and other mineral elements such as calcium, phosphorus, iron, zinc, and selenium (Li *et al*. 2017). The study recommends rationalized forest management and minimizing human intervention for long-term conservation.

## Conclusion

*C. quadrangularis* dominated in shrub life form with an importance value index of 106.40, a total of 3,488 individuals, with an average density of 1.4 individual.m $^{-2}$. The spread rate of *C. quadrangularis* was estimated at 422 $m^2$.$year^{-1}$ with a radial distribution pattern. The total biomass of *C. quadrangularis* was 12.66 $Mg.ha^{-1}$. *C. quadrangularis* density had a weak negative linear correlation with species richness and abundance of the tree, shrub, herb, and bamboo regeneration.

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