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REVIEW PAPER

Impacts of bamboo spreading: a review

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Abstract
Bamboo has been receiving increased attention as a renewable resource owing to its fast growth, economic value, widespread availability, and physical properties. However, environmental impacts of such intensive bamboo cultivation need to be assessed in order to avoid any negative consequences that could result from this plant's invasive potential. In this study, we sought to evaluate the possible implications of bamboo growth in diverse ecosystems, as well as its relations with riparian zones and local hydrology. We reviewed studies that have focused on cultivation of bamboo in various areas where they are not always native. Furthermore, we have provided an objective compilation of studies that report possible effects and impacts that bamboo may have in local landscapes where it has been introduced or established. We conclude that, regardless of bamboo being native or exotic in a region, it can become invasive in some ecosystems, even when a bamboo species does not show spreading characteristics. Introduction of bamboo in a new area needs preliminary studies to avoid the species that may become invasive and to minimize the risk of suppression of different stages of ecological succession in local vegetation and of the changes in the forest structure and diversity.

Keywords Local vegetation · Diversity · Invasive character · Native plant · Exotic plant

Introduction

Bamboo has been receiving increased attention as a renewable resource owing to its fast growth, economic value, large availability, and physical properties comparable to that of wood (Engler et al. 2012; Mahdavi et al. 2010). Many researchers (Barlow et al. 2012; Datillo and Rhoades 2005) have focused on the potential use of bamboo for reforestation of degraded areas because of its ability to quickly spread and develop, in controlling soil

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erosions, and for the stabilization of banks in riparian zones. According to Van der Lugt et al. (2008), Non-Wood Forest Products (NWFP), like bamboo, play an important role in mitigation of pressure on forest resources like wood that are in increasing demand but have slow growth.

Bamboo management on a big scale represents a relatively recent development. Studies assessing the environmental impacts of this new way of culture are necessary to avoid any negative consequences that may arise because of its potentially invasive character. Judziewicz et al. (1999) emphasizes that the life cycle, structure, evolution, and ecology of bamboos must be evaluated in a contextualized manner in forest ecosystems. As demonstrated by Lobovikov et al. (2012), bamboo is an intriguing option, but not a solution for mitigation and adjustment to problems arising because of timber resource scarcity.

In this context, this study reviews the establishment of bamboo in several regions and evaluate the possible implications of bamboo spread on forest ecosystems, as well as its relationships with riparian zones and local hydrology. We emphasize that the sustainability of an environment depends, in most cases, on the presence of native vegetation.

Bamboo: characteristics and global distribution

Bamboo belongs to the subfamily Bambusoideae with approximately 115 genera and 1450 species (Wysocki et al. 2015). Bamboo differs from the other grass species because of its evergreen habit, well-developed rhizomes, presence of culm, pseudo-petiolar leaves, distinctive foliar anatomy, non-seasonal flowering, and variation in the number of chromosomes (Clark 1990). Some bamboos reproduce sexually and others asexually by underground stems with wide clumps, which are often resistant to fire impacts (Mews et al. 2013). According to Liu et al. (2017) many bamboos flower only once before they die.

Native species of bamboo have been described from almost all continents. China has 500 bamboo species belonging to 48 genera (Chen et al. 2009), India has 148 species and 29 genera (Sharma and Nirmala 2015), while Japan has 84 species described (Bystriakova et al. 2003). Londoño (1998) affirms that in Latin America has 20 genus and 429 species. According to Greco et al. (2015), Brazil has a high bamboo diversity with 256 species, of which 176 are endemic.

To understand the ecological characteristics of quick growth in a habitat, some studies have focused on the invasive potential of bamboo in habitats where they have been introduced. Richardson et al. (2000) define alien plants as plant taxa in a given area whose presence there is due to intentional or accidental introduction as a result of human activity (synonyms: exotic plants, non-native plants; non-indigenous plants). The same authors define invasive plants as naturalized plants that produce reproductive offspring, often in very large numbers, at considerable distances from the parent plants (approximate spatial and time scales to classify a plant as an invasive species are as follows: for taxa spreading by seeds and other propagules, the distance criteria is >100 m from the parent population in <50 years; for taxa spreading by roots, rhizomes, stolons, or creeping stems, the distance is >6 m in 3 years). Thus, these species have the potential to spread over a considerable area. PySek (1995) affirms that species can only be regarded as native to a given area if its occurrence is independent of human activities. However, those species that arrived before the beginning of the Neolithic period should also be considered as native, even if introduced by man.

An invasive exotic species is defined as any species capable of propagating that is not native to that ecosystem, and whose introduction causes, or is likely to cause, environmental harm (Council 2006). The invasive exotic species, when introduced in new environments, can develop into dominant populations. Often, when they take over the space occupied by the native species, changes in the natural ecosystem processes result, promoting negative environmental and socioeconomic impacts. According to Coradin and Tortato (2006), anthropogenic activities involving animals and plants for food and construction industry, among others, contribute considerably to the dissemination of invasive exotic species.

Canavan et al. (2017) compiled an inventory of bamboo species and their spatial distributions, determined which species have been introduced and have become invasive outside their native ranges, and explored the correlation between introduction and invasion. The authors verified that the introduction of species correlated with certain traits: taxa with larger culm dimensions were significantly more likely to have been moved to new areas; and those with many cultivars had a higher rate of dissemination and invasion. They suggest that it is difficult to determine whether the patterns of introduction and invasion are due simply to differences in propagation methods, or whether humans have deliberately selected inherently invasive taxa. However, the authors affirm that, as bamboos are more widely used, the number and impact of invasions will increase, unless environmental risks are carefully managed.

According to Liu et al. (2018) the main application of bamboo in China is divided into two parts: economic use and ecological utilization. The economic utilization can be roughly divided into timber bamboo, shoots bamboo, skin bamboo, and art and crafts bamboo. Ecological value can be divided into water conservation forest and ecological forest tourism. The authors also affirms that bamboo species, particularly the large clump bamboo, have enormous potential as an energy source. According to Canavan and Richardson (2015) bamboos have been cultivate in different parts of the world and this, has likely, and resulted in shift of the species of interest over the last century, as different species may offer different merits depending on the purpose. The authors also say that if cultivation is for agroforestry, large-statured and straight culmed species are preferred; for textiles and weaved goods, species with long culm internodes are often chosen; for biofuel production, attributes such as fast-growth rates are needed.

Filgueiras and Gonçalves (2004) conducted a checklist of the basal grasses and true bamboos that were native to Brazil and listed the 20 most commonly cultivated bamboo species in the country. Kawakita et al. (2016), in characterizing Poaceae from upper Paraná river floodplain and its surrounding areas, reported the presence of exotic bamboo species belonging to the genus Bambusa and Phyllostachys in the area. Bamboo makes use of available resources competitively, and even in regions where they are native, they may take on an invasive character in fragile environments (Table 1).

Risk assesment

According to the National Invasive Species Council (2001), a species that is nonnative to the ecosystem under consideration and whose introduction causes, or is likely to cause, economic or environmental harm or harm to human health is defined as an invasive species. Shackleton et al. (2019) affirm that, based on the findings, there are a number of considerations that should be made in the future relating to policy, governance and management of

Table 1 Characteristics of some bamboo species and their impacts

Genus	Distribution	Species	Origin	Characteristics	Impacts generated by bamboo dispersion and competition
Actinocladum	Brazil and Bolivia (PROTA 2017)	*Actinocladum verticillatum*	Brazil (Filgueiras and Gonçalves 2004)	Vegetative dispersion by pachymorphic rhizomes covered by hard scales resistant to fire. Grow in clumps reaching up to 4 m high (Filgueiras and Gonçalves 2004)	Occupies space and reduces the luminous incidence generated by bamboo clumps hampering the germination of seeds and the establishment of seedlings of arbustive-arboreal species, selecting those that are most tolerant to shading, thus modifying the floristic composition and vegetation structure (Silvério et al. 2010)
Bambusa	China, Australia, Mexico, Taiwan, Benin, Papua New Guinea, the Reunion Islands (GBIF, 2017a), USA, Costa Rica, Colombia, Germany, Thailand, Argentina, Honduras, Uruguay, Japan, Brazil (GBIF 2017b, c, d)	*Bambusa tuldoides*	Vietnam and South of China (Ohrnberger 1999)	Pan tropical distribution with vegetative dispersion through pachymorphic rhizomes, reaches 6 to 10 m high, resistant to frosts up to − 7 °C (Ohrnberger 1999)	The high density of *Bambusa tuldoides* affects the diversity of natural regeneration, changing the establishment and perpetuation of the plant species (Felker et al. 2017)
		Bambusa vulgaris	Madagascar and South of China (Ohrnberger 1999)	Pan tropical distribution from low elevations up to 1200 m on river banks, waste lands, forest edges, secondary forest, and disturbed forests (Ohrnberger 1999). Vegetative dispersion by pachymorphic rhizomes, stem divisions and cuttings of branches, and less often by seeds (PROTA 2017)	It grows compounding wide mono-specific areas that overlap the native vegetation, shading native plants and monopolizing resources (Blundell et al. 2003). In Hawaii, it is considered a harmful species because it assumes and overlaps all the vegetation in wet areas where it develops (Little et al. 2003)

Table 1 (continued)

Genus	Distribution	Species	Origin	Characteristics	Impacts generated by bamboo dispersion and competition
Guadua	Brazil, Bolivia, Peru (GBIF 2017e)	*Guadua sarcocarpa*	Amazon Forest (Peru, Brazil, and Bolivia) (Londono and Peterson 1991)	Vegetative dispersion by pachymorphic rhizomes, with stems reaching from 0 to 30 m height. Shrubby and thorny bamboo (Londono and Peterson 1991). It is the first species of the genus known by its fleshy fruit and the first edible bamboo reported from Latin America, it grows in tropical forests or in transition forests (bamboo forests) (Londono and Peterson 1991)	It impedes forest succession by causing the death of younger individuals (Londono and Peterson 1991). Its dissemination and dominance in the native forests are aided by forest fires (Smith and Nelson 2011)
		Guadua tagoara	Atlantic Forest (Fantini and Guries 2000; Rother et al. 2016)	Dispersion by pachymorphic rhizomes with ascendant and climber habit (Judziewicz et al. 1999). Adult plants grow up to 20 m in height, develop spinescent side branches that extend to 6 m length over and among the neighboring trees; however the side branches do not develop in the basal parts of the stems (Londoño and Clark 2002)	High invasive potential, dominating wide secondary forest areas by reducing the density and basal area of arboreal plants (Fantini and Guries 2000). It affects arboreal plant regeneration by limiting dispersion of seeds and affecting the survival of seedlings (Rother et al. 2009; Griscom and Ashton 2003)

Table 1 (continued)

Genus	Distribution	Species	Origin	Characteristics	Impacts generated by bamboo dispersion and competition
Phyllostachys	Taiwan, Australia, New Zealand, Mexico, Ecuador, Honduras, Costa Rica, Brazil, Argentina, Bolivia, Spain, United Kingdom (GBIF 2017f), France (Valkenburg et al. 2014), Madagascar (Kull et al. 2012)	*Phyllostachys aurea*	Native from China and Japan (Weakley 2008)	Leptomorphic rhizomes that confer spreading habit to the population. If it is not managed properly, it can become hard to eradicate; aggressive invader, spreading and invading large areas (Filgueiras 2005)	This bamboo was rated as High Risk under the Plant Protection and Quarantine’s-weed risk assessment model due to its abilondy to spread widely and quickly by means of rhizomes, compound dense thickets, causing damages to structures and roads, and due to its status of weed in many areas (County 2016a). It invades the secondary forests, clearings, and forest edges in many areas (Gucker 2009) and replaces the native species (Kaufman and Kaufman 2013; Swearingen and Bargeron 2011). The leaves that are carried along the streams modify the ecosystem processes, changing the food chains flow starting with the detritivore invertebrates (Gonzalez and Christoffersen 2006)

Table 1 (continued)

Genus	Distribution	Species	Origin	Characteristics	Impacts generated by bamboo dispersion and competition
		Phyllostachys pubescens	China (Weakley 2008)	Leptomorphic rhizome system that grows laterally, allowing quick and generalized expansion of ramets (Makita, 1998). The saplings reach 10–20 m height rapidly (Suzuki 2015)	The native vegetation can be reduced through the allelopathic and phytotoxic effect of the bamboo (Chou and Yang 1982). It promotes the increasing of soil pH (Umemura and Takenaka, 2015), increasing in the average surface runoff and sediment loading compared to native forests in second succession stage (Zhou et al. 2012) and forests with high plant diversity (Shen et al. 2016)

invasive species to ensure sustainable livelihood strategies and outcomes, improve adaptive capacity and to ensure that communities are not made more vulnerable by invasive alien species. According to Perkins et al. (2011), the risk of invasion increases as the resistance to invasion provided by the biotic characteristics present at a site decreases. Many countries have highlighted the urgent need for more rigorous and comprehensive risk analysis frameworks for non-indigenous species (McNeely et al. 2001).

To develop an appropriate framework, we need to recognize that risk analysis of species invasions is inherently an interdisciplinary problem, involving ecology, economics and mathematics (Leung et al. 2002). Some authors improved risk assessments frameworks. Leung et al. (2002) presented a quantitative bioeconomic modelling framework to analyze risks from non-indigenous species to economic activity and the environment. Perkins et al. (2011) introduced the invasion triangle and describe how it can be used, provide examples of invasion triangle application, and discuss the uses of it from a conceptual framework into a quantitative model. The authors define the three sides of the triangle invasion as: invader attributes, site biotic characteristics, and site environmental conditions. Koop et al. (2012) developed a weed risk assessment model for the entire United States. The authors affirm that the tool uses two elements of risk, establishment/spread potential and impact potential, in a logistic regression model to evaluate the invasive/weedy potential of a species. Weber and Gut (2004) developed a risk assessment system to assess the invasion potential of new environmental weeds in central Europe. Phelong et al. (1999) developed a Weed Risk Assessment system with on 49 questions based on main attributes and impacts of weeds. According to the authors a weed risk assessment model with explicit scoring of biological, ecological, and geographical attributes is a useful biosecurity tool for detecting potentially invasive weeds in many areas of the world.

Gordon et al. (2008) affirm that the Australian Weed Risk Assessment (WRA) is currently used within the plant introduction regulations of both Australia and New Zealand to prevent importation of new plant species likely to become invasive, and has been tested in a number of other countries. The Australian Weed Risk Assessment (AWRA) system is considered, for many researchers, easy to use and is one of the most popular weed risk assessment tools available. The Australian WRA tool has been tested and applied in countries or regions with various geographical conditions: Hawaiian Islands (Daehler and Carino 2000); Bonin Islands (Kato et al. 2006); Czech Republic (Křivánek and Pyšek 2006); Tanzania (Dawson et al. 2009); Mediterranean Central Italy (Crosti et al. 2010); Portugal (Morais et al. 2017); China (He et al. 2018). According to Yi (2008), in China the second largest category of alien weeds are in the Poaceae family.

According to USDA—United States Department of Agriculture (2019), the “Guidelines for the USDA-APHIS PPQ Weed Risk Assessment Process”, during the development of a WRA, authors gather scientific evidence and other information for answering a series of questions that characterize the risk posed by the plant taxon organized into the four risk elements: Establishment/Spread (ES) Potential (23 questions); Impact Potential (18 questions); Geographic Potential (36 questions); Entry Potential (12 questions). County (2016a, b) made the WRA analysis of the golden bamboo and of the yellow groove bamboo. County (2016a) conclude that golden bamboo is high risk. According to them, the rhizomes of bamboos, including the golden bamboo, may sometimes extend 15 to 25 feet from the originating plant, and these growth habit makes difficult to control it in gardens and urban plantings.

Lieurance et al. (2018) used a WRA tool to evaluate and compare invasion risk of non-native running and clumping bamboo species in the continental United States. The authors found that running bamboo species present a significantly higher invasion risk than clumping species. According to the authors, only one running bamboo species (*Chimonobambusa tumidissinoda*) was identified as low risk and one clumping species (*Bambusa bambos*) was high risk for invasion.

Canavan et al. (2019) reviewed the literature on the environmental impacts caused by invasion and expansion of bamboos. They find that, contrary to the situation in many other plant groups, biogeographic origin was not a strong predictor of the type and severity of environmental impacts caused for bamboos. The authors argue that impacts from bamboos are a response to land transformation and disturbance of forest habitats by humans. The authors associated the impacts of bamboos in four mechanisms defined by Hawkins et al. (2015): 1—competition, 2—poisoning/toxicity, 3—structural changes to an ecosystem, and 4—chemical changes to an ecosystem, and they conclude that the mechanism that most frequently led to impacts was 1, followed by 4.

Bamboo species, running bamboo *Phyllostachys* spp., and clumping *Bambusa* spp., spread into natural environments in South East Queensland and northern New South Wales, Australia (Queensland Government 2015). In the State of New South Wales (NSW), Australia—*Arundinaria* spp. (*Arundinaria pusilla*, *Arundinaria simonii*, *Vietnamosasa pusilla*) and *Phyllostachys aurea* are declared a “Regionally controlled weed” (Pagad 2016). *Phyllostachys* spp. is declared a ‘Regionally and Locally controlled weed”. According to Pagad (2016) the Legislation states that “relevant local control authority must be promptly notified of the presence of this weed and it must be fully and continuously suppressed and destroyed” on Lord Howe Island.

Hydrologic behavior of areas occupied by bamboo

In a study conducted in the subtropical areas of Southeastern China, Zhou et al. (2012) compared a native forest in the secondary stage of regeneration and a forest replanted with only moso bamboo (*Phyllostachys pubescens*). After 6 months of observation, and a total precipitation of 1220.8 mm, the average surface runoff coefficient of the areas was 0.18% in the purely bamboo forest and 0.10% in the native forest in secondary stage of regeneration. For the same period, it was observed that the total sediment loading was 126.3 kg ha^{-1} (1.034 kg (ha mm)$^{-1}$ per run-off depth) and 31.99 kg ha^{-1} (0.262 kg (ha mm)$^{-1}$ per run-off depth) in the bamboo and natural secondary forests, respectively. The authors conclude that the sediment yield for moso bamboo forest is three times higher than that of natural secondary forest.

In a study conducted in southern China, Shen et al. (2016) observed the surface runoff coefficient and sediment loading between a purely bamboo forest and two mixed bamboo forests. The maximum values were observed for a precipitation of 70 mm. A 10% runoff coefficient and 270.00 kg ha^{-1} sediment loading were observed for the purely bamboo forest. For the mixed forest of bamboo composed of *Cleyera japonica* and *Hemerocallis*, 8% runoff coefficient and 119 kg ha^{-1} sediment loading were obtained. For the mixed forest composed of Japanese *Cleyera*, 6% runoff coefficient and 196 kg ha^{-1} of sediment loading were estimated.

The values of surface runoff and sediment loadings in prevalent bamboo forests start to show significant differences in comparison with forests having more vegetation diversity only during greater precipitations, as seen in the study undertaken by Ide et al. (2010). Wang and Liu (1995) collected hydrological data from three different forests in South China: a moso-bamboo forest (*Phyllostachys pubescens*), *Cunninghamia lanceolata* forest, and a broad-leaved natural forest, so it was possible to observe that the moso-bamboo forest was efficient in flow peaks reduction and increase of the slow flows, consequently it demonstrates to be less affected by the seasonal precipitation variations.

Evaporation is an important variable that affects water balance and, consequently, the hydrology of a region. Komatsu et al. (2010) analyzed the evaporation for a moso bamboo (*Phyllostachys pubescens*) forest and compared this with six other coniferous forests in Western China. The annual value of evaporation obtained in the moso bamboo forest (567 mm) was higher than the average recorded in the other forests. According to the authors, this difference occurs mainly due to the transpiration properties of bamboo and not as a result of climatic differences.

Bamboo in fragile forest areas

The establishment of bamboo in an area can occur quickly. This is seen to occur even in some forests where bamboo is a native species (Wong 1991). Bamboo is grown in an area not only for reforestation, but also to control erosion, and as a raw material for civil constructions. Owing to this diversity of its usage, in many regions around the world, bamboo production is encouraged. In Brazil, a National law, Law n. 12.484 (Brasil 2011), promoting the sustainable management and cultivation of bamboo has been set up, and the planting of exotic forest bamboo has been encouraged without taking into consideration the impacts on the native vegetation in the areas where they are being introduced. Bamboos have competitive characteristics and can become invasive even in regions where they are part of the native vegetation. Studies to mitigate or control this process have been undertaken. For example, Felker et al. (2017) observed that secondary species demonstrate more potential for adaptation in environments dominated by arboreous bamboo, and suggest that they can act as key-species for future actions of management and recovery.

Sometimes bamboos are presented as a solution to economic, social, and reforestation problems. However, after their establishment, it is hard to control their spread (Blundell et al. 2003). The high invasive capacity of bamboos can remove other highly competitive pioneer species, thus decreasing their abundance, or even, according to Griscom and Ashton (2003), impede forest succession by causing the death of younger plants. Judziewicz et al. (1999) affirm that for the efficient capture of light by bamboos, there is a strong association between the space occupied by bamboos and the way their stems grow from the rhizomes. According to Araujo (2008), it is possible, amidst dense vegetation, to identify large bamboo clumps when they reach the forest canopy, distinguishing themselves in the vegetation structure.

Considering that bamboos exert a negative influence on the plant community Rother et al. (2016) investigated how this influence manifests at the population level of *Euterpe edulis*. Their study showed that *Guadua tagoara* was functioning as a demographic bottleneck for the natural population of *E. edulis* by arresting its later stages of regeneration, and that at high densities the bamboo might limit recruitment of this palm species.

Further, Felker et al. (2017) carried out a study in South Brazil to compare a riparian forest area without bamboo (SB) and other riparian areas where native vegetation had been replaced by *Bambusa tuldoides* (CB). In this study the phytosociological indexes, floristic composition, Shannon diversity index, Margalef richness, Simpson Dominance, Sorensen similarity, and Twinspan grouping were analyzed. The results obtained indicated that the abundance and the absolute density of vegetation were lower in CB than in SB. Thus, the authors concluded that *Bambusa tuldoides* thickets affected the natural regeneration of the local vegetation, changing the establishment and perpetuation of native species.

Silvério et al. (2010) analyzed areas in the Brazilian Cerrado and Cerradão and determined that *Actinocladum verticillatum* thickets affected the quantity and diversity of species negatively in its vicinity. It was observed that the spreading of this bamboo reduced water, light, and space availability. Therefore, bamboo clumps presented a competitive relation with the small-sized plants and the Cerrado native woody plants, complicating their germination. Da Silva et al. (2013) noted the invasive behavior of *Bambusa vulgaris* in an Atlantic Forest reserve at the City Park in Maceio, Brazil, where bamboos were introduced in 1996 for trail demarcation and since then they have spread at a speed of 0.82 ha $year^{-1}$. According to the authors, this behavior is mainly due to the clumping and pachymorphic characteristic of bamboo, as well as the lack of predators or other similar competitive individuals.

An important characteristic of bamboo is that it is highly flammable (Gielis 2002; Sinha and Bajpai 2009), contributing as a fuel to both natural fires and fires caused by human activities. Bamboo benefits from burning of native vegetation, wherein its ability to quickly spread is further enhanced after a fire because the area gets exposed to the sun and nutrients in the soil become available. This was pointed out in the study carried out by Smith and Nelson (2011), in which they concluded that forest fires aid the spreading and dominance of the species belonging to the genus *Guadua* in native forests. They also observed that in the soil-fire experiment, the density of bamboo stalk recovered more quickly than plant basal area, and it took 3 years for the basal area in the burnt plot of bamboo to approach values similar to that in the control plot.

The competitive behavior of bamboo can be a problem not only in areas where they are introduced, but also where they are native. Fantini and Guries (2000) have reported that *Guadua tagoara* was considered a bamboo with high invasive potential, dominating large areas of secondary forests. The dominance of this bamboo is associated with the decrease in the density and basal area of arboreous plants, and with extreme modifications to the forest structure. Rother et al. (2009), in a study undertaken in the Atlantic Forests in Southeast Brazil, verified that the presence of *Guadua tagoara* affects the regeneration of arboreous plants by preventing the spread of seeds and the survival of saplings.

Griscom and Ashton (2003) offered a conceptual pattern to evaluate bamboo invasion and dominance in forest plots in Southwestern Amazon. The authors observed that forest succession was arrested in plots dominated by *Guadua sarcocarpa*, as evidenced from the size-class distribution of trees and sapling mortality. The percentage of seedling mortality was over twice as high in the forest plots dominated by bamboos than in plots of forests without bamboos. The data about soil water content and the damage to the seedling stalks suggest that root competition and mechanical crush by bamboo is the cause for the arrested forest phenomenon. The soil water content (0–10 cm) was significantly lower in plots with bamboo. Seedlings with stalks of a particular/specific diameter were, on an average, 29% higher in plots without bamboo. The authors concluded that the occurrence of forests dominated by bamboos can be explained by interplay between the mechanical properties, wind disturbance, and elevated rates of tree mortality in the presence of bamboo.

Tripathi and Singh (1994) studied *Dendrocalamus strictus*, in bamboo savannas in the Indian dry tropics, and observed that the annual allocation (83%) of dry matter was mostly to the underground parts. This resulted in the development of a large root system that was able to absorb substantial quantities of water and nutrients from a soil limited in these resources. The production rate of roots/saplings in bamboo savannas was considerably higher than that in natural forests of *Shorea robusta*. These researchers concluded that, under strong biotic and abiotic pressures, bamboo in the savanna region tends to speed up the accumulation of underground rhizomes, using N and P efficiently through internal cycling, and conserve these nutrients by accumulating them in underground parts and immobilizing them in the decomposing leaf mass in the soil of the savanna.

Besides the physical effects, Umemura and Takenaka (2015) highlighted the chemical effects caused to the soil by the spreading of the bamboo *Phyllostachys pubescens*, emphasizing mainly the increase in the soil pH. This study was carried out in three areas that were invaded by bamboos in Central Japan and noted that the cations of Ca available in the soil was higher in regions with bamboo.

In a comparative study on the competitive potential of *Phyllostachys edulis*, *Cryptomeria japonica*, and the native vegetation in Taiwan, Chou and Yang (1982) reported the allelopathic capacity of bamboo and concluded that the quick invasion of *Phyllostachys pubescens* in its forests and in bordering forests was facilitated mainly by: (1) the quick growth of rhizomes that possibly can free the phytotoxic exudates of roots, and (2) allelopathic substances produced by bamboo leaves and the burlap on decomposition. The continuous release of soluble phytotoxins in water by *Phyllostachys pubescens* and the accumulation of these compounds in the soil can result either in the suppression of the undergrowth or in the elimination of the neighboring plants, thus influencing the diversity and distribution of species in the undergrowth.

Bamboo in riparian zones

Riparian areas are the interfaces between terrestrial and aquatic ecosystems that cover sharp gradients of environmental factors, ecological processes, and plant communities. According to Gregory et al. (1991), these zones are not easily defined, but they are constituted of land mosaics, communities, and environments inside a bigger landscape. Corenblit et al. (2007) affirm that these zones, when healthy, offer important ecosystem services, including improved forage, habitats for various animals, and reduced flooding impacts. The riparian ecosystems show a variety of physiological properties that let them resist and recover from disturbances, in addition to providing stability to the soil and the flood plain.

Leaves accumulated at the bottom of streams can be crucial determinants of the structure of the aquatic community by generating heterogeneous microhabitats for fauna (Friberg and Winterbourn 1997). However, bamboos provide mono-specific support in the riparian zones (Gadgil and Prasad 1984) and once established they cause changes in the structure and diversity of the plant communities in these zones.

O’Connor et al. (2000) conducted a study in riparian areas of mountains in Luquillo, Puerto Rico, and verified that the alien bamboo leaf fall exceeds that of the native mixed-species forests. When bamboo emerges in riparian zones, bamboo leaves that fall in the water body decompose and result in quick leaching of elements. Besides, the introduced bamboos can affect the native macro-invertebrates through changes in food resources and habitat, typically supplied by the foliage from the various species in the native riparian forests.

Barlow et al. (2012) justifies planting of bamboos in the riparian zones based on its extended system of fibrous roots and somewhat dense burlap. Such characteristics protect the plant against surface runoff caused by rain, and it also can help in controlling soil erosion. However, Felker et al. (2017) evaluated the impact of *Bambusa tuldoides* on natural regeneration in a riparian forest in the Rio Grande do Sul, south of Brazil, and concluded that there was a loss of diversity and abundance in riparian zones where bamboo was introduced.

Conclusion

Projects that involve the planting of native or exotic bamboos face obstacles, as they lack applicable definitions and evaluation methods, and there are gaps in the knowledge about the effect of bamboos on the ecosystem.

Bamboo is an extremely adaptable and competitive plant. Thus, regardless of being native or exotic from a region, it can become invasive in a fragile area. This includes even those species that are not spreading by nature.

Bamboo provides more water infiltration in the soil surface layers. However, a forest with more plant diversity is more efficient in the containment of erosion and sediment production than exclusive bamboo forests.

Introducing bamboo in a new area needs continuous monitoring in order to avoid invasion by this plant and minimizing the risk of suppression of the stages of ecological succession of local vegetation and the changes in forest structure and diversity.

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Compliance with ethical standards

Conflict of interest The authors have no competing interests to declare.

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