

*Discussing the Consequences of  
Utilising Non-native Bamboo Species in  
the Context of Forest and Soil  
Reclamation*

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***Declaration of Independent Study (German)***

*Hiermit erkläre ich, dass ich die vorliegende Hausarbeit mit dem Thema “Discussing the consequences of utilising non-native bamboo species in the context of forest and soil reclamation” ohne fremde Hilfe erstellt habe. Alle verwendeten Quellen wurden angegeben. Ich versichere, dass ich bisher keine Studien- oder Prüfungsarbeit mit gleichem oder ähnlichem Thema an der FernUniversität oder an einer anderen Hochschule eingereicht habe.*

A handwritten signature in blue ink, appearing to read 'Dohrmann', with a long horizontal flourish extending to the right.

*(Christian Dohrmann)*

*Bangkok, 10. Mai 2020*

## 1. Introduction

Bamboo has been re-discovered as a fast-growing miracle plant with, for instance, high productivity due to quick growth, soil stabilising attributes, high carbon sequestration and multiple use in the manufacturing industry (Canavan et al., 2016: 2; Cleuren, 2007: 69; Jijeesh, 2009: 8). Bamboo has been used in the restoration of lost or degraded forests and soils in the regions of India, China, South America and Africa (e.g. Xu et al., 2020; FAO and INBAR, 2018). In particular, the International Network for Bamboo and Rattan (INBAR) promotes the use of bamboo for environmental regeneration efforts, among many other reasons. INBAR has highlighted bamboo's capacity to grow at rapid rates aboveground and belowground, through which it positively impacts on the surrounding biosphere and lithosphere (FAO and INBAR, 2018; Lou and Henley, 2010; Kuehl, Henley and Lou, 2013). It is said to revegetate and restore productivity to barren land over a short period of time (FAO & INBAR, 2018: 1).

While it shall be acknowledged that bamboo can be used as a versatile tool to halt and reverse the degradation of an ecosystem, the introduction of bamboo species to a non-native environment cannot be left disregarded. It appears that the invasiveness of bamboo is understudied as there seem to be not “any comprehensive studies on the invasion ecology of bamboos, despite their reputation for being a group that contains highly ‘invasive’ species” (Canavan et al. 2016: 2).

In this context, the present paper is meant to serve as critical source on the documented effects which bamboo can have within the scope of forest and soil reclamation and whether or not it poses a threat to the natural environment it was introduced to. To evaluate the topic at hand, first, the general characteristics of bamboo are summarised. Second, an important reason for the spread of bamboo into non-native geographical regions is demonstrated with a brief policy review from Kenya to illustrate the undergirding economic but not ecological interests. Third, the reasons why bamboo finds attention in landscape reclamation efforts are compiled. Fourth and subsequently, the observed consequences for the natural environment after introducing bamboo are discussed by applying predefined mechanisms of invasiveness (by Hawkins et al. 2015; Wittenberg and Cock, 2001). This discussion leads into the cascading systemic consequences for biodiversity. Finally, the discussions are summarised into an evaluation of when bamboo may and may not be a threat in forest and soil restoration and what angles will need to be pursued for better informed research on bamboo. The main points distil into distinguishing between whether land is barren or already vegetated and the subsequent purposes for introducing bamboo species.

## 2. Methodology

The paper's methodology rests exclusively in collecting, compiling and analysing secondary source material. Research articles and case studies have been drawn from various academic authors as well as research and development organisations. The purpose of this method was to compile, identify and discuss the consequences of introducing bamboo to environments where it is not a native species.

While the chapters 4 and 5 are meant to provide a general and critical overview over why bamboo as a plant has become of much interest, the chapter 6 and 7 represent the core of this paper. With chapter 6, the commonly found reasons for why bamboo is used in forest and soil reclamation efforts are summarised. Those findings are then contrasted in chapter 7 with regards to their consequences on the natural environment from angles of individual factors as well as a systemic view for biodiversity.

To facilitate the discussion of bamboo's impacts in chapter 7, the invasiveness frameworks by Hawkins et al. (2015) and Wittenberg and Cock (2001) have been applied. These frameworks proved relevant in order to distil and categorise the potential consequences bamboo can have.

Relevant information was extracted on:

- the geographical origins of bamboo;
- the bamboo genus, type and variety differences and their origins;
- reasons why bamboo species are used in reclamation efforts; and
- the manifold and cascading consequences of bamboo interacting with the environment.

### 3. Characteristics of bamboo

Bamboo can be found across the world, mostly “in tropical to warm temperate ecosystems, with some diversity in cold temperate regions” (Vorontsova, 2016: 6).

Bamboo is endemic to every continent, with the exception of Europe and Antarctica, and

grows from sea level to over 4000 m in mainly forest and mountainous grassland (Kelchner and Bamboo Phylogeny Group, 2013: 404).

Figure 1: Indicative map of the distribution of bamboo



Source: Kelchner and Bamboo Phylogeny Group, 2013: 406.

Bamboo taxonomically belongs to the grass family Poaceae, the subfamily Bambusoideae, and comprises three genera: tropical woody bamboos (Bambuseae), temperate woody bamboos (Arundinarieae) and herbaceous bamboos (Olyreae) (Wysocki et al., 2015; Vorontsova, 2016: 6; Xu et al., 2019: 1).

Due to poor definitions, rudimentary forest inventories and neglect of the resource, data on bamboo areas are notoriously unreliable (Lobovikov, 2009: 15). Depending on the source and age of the publication, the documented and reported number of bamboo species varies. Canavan et al. (2016:1) speak of 1662 bamboo species, while INBAR (2016: 6) speaks of 1642 species. Other sources, such as Xu et al. (2019: 1) cite much fewer species with above 1400. The reason for these differences is likely to be attributed to extensive knowledge gaps for tropical plants that are often impossible to identify, in addition to new information being published sporadically in a broad range of literature, which in itself is difficult to find (INBAR 2016: 5).

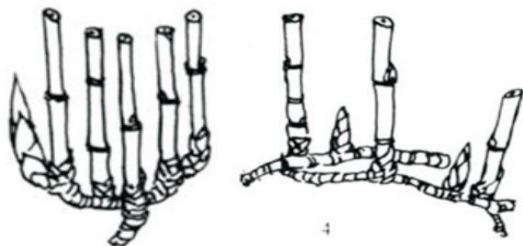
Bamboo receives increasing attention due to its rapid growth rate. Under optimal conditions, bamboo culms may elongate by 50 cm to 125 cm a week, reach final height within two to four months and maturity within only three to seven years, while some subspecies (i.e. Moso bamboo) grow up to 1.2 m per day (Lobovikov et al. 2009, Fu 2001).

The main structural parts of a bamboo plant are the underground system of solid or hollow rhizomes<sup>1</sup>, the aboveground culms, and the culm branches with their sheaths and leaves. Rhizomes are not roots but underground shoots. Colourless storage- and propagation organs, they have dense, fibrous roots and branch off the mother plant, thus colonizing new territory. (Lobovikov, 2009: 10).

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<sup>1</sup> rhizome: The segmented, complex, subterranean stem system (the "root stock" of a bamboo plant; present in two basic types —monopodial (leptomorph) and sympodial (pachymorph). (Lobovikov, 2009: 41)

Figure 2: Sympodial (left) vs monopodial (right) bamboo



Source: Tekpetey, 2011: 4.

Bamboos are classified into two major groups: leptomorph / monopodial (also called running) and pachymorph / sympodial (also called clumping) (as in Tekpetey, 2011; Canavan et. al, 2016). Mixpodial also exist (Tekpetey, 2011: 5).

The monopodial or running group allows them to spread more rapidly than other plant species, including the clumping bamboo group (Canavan et al., 2019: 125). The rhizomes typically occupy the top 30-50 cm of soil and may spread for tens of metres (Scurlock, 2000: 4). Running or monopodial bamboos are mostly found in the subtropical and temperate regions, and clumping (or sympodial) bamboos in the tropical and subtropical regions (Scurlock, 2000: 4, Canavan et al., 2019: 125). Species from China and Japan have running species.

Bamboos form buds on the side of the rhizomes, which extent underground and eventually form an upright shoot as well as extending the rhizome. Aboveground, growth takes place in form of elongation of internodes, “as much as 0.5 m/week in the case of tall bamboos” (Scurlock, 2000: 4). Nearing its final growth, sheaths are shed and branches with leaves emerge from the internodes, primarily at the top of the culm. The leaves are shed at the end of every growing season or during the following growing season, depending on the species, and reflect a biennial pattern (Scurlock, 2000: 4). Further growth sees only the thickening of the culm walls, increasing the wood density (Scurlock, 2000: 4).

Some bamboo species flower annually to disperse their seed, while other if not most species take supra-annual intervals to flower, ranging between 3 and 120 years depending on the species (Janzen, 1976: 347, 354). Those species which do not flower annually die off after their flowering cycles (ibid.). The same flowering may be avoided through human harvesting interventions.

#### 4. Why are non-native bamboo species used?

Before going into the ecological aspects of why bamboo finds attention, it needs to be understood that the utilisation of bamboo is not exclusively promoted for ecological but also economic benefits. Bamboo experiences a rediscovery as a fast-growing timber substitute due to its growth, environmental and engineering properties (e.g. Akwada and Akinlabi, 2018; Manish Kumar, 2015: 81). In fact, it became dubbed as “the poor man’s timber” or “poor man’s carbon sink” (Bowyer et al., 2005; Lobovikov et al., 2009, Manish Kumar, 2015). Its potential for different products makes it an important material for employment generation and economic gains (ibid.). This very “societal and economic significance has led to increased bamboo cultivation globally” (Xu et al., 2020: 1).

Although estimates can vary depending on definition and time of documentation, and new bamboo species keep being discovered (e.g. Sungkaew, 2007), to date above 1600 bamboo species (Canavan et al., 2016:1; Vorontsova, 2016: 6) have been documented as native to tropical and subtropical regions around the world. Given that bamboo species can be found around the world, one might presume that it would make most sense to utilise bamboo species from the indigenous environment where they originated. As it turns out, however, this is not the case. Bamboo species have been moved around the world by human activity, making it a “global-scale natural experiment in biogeography” (Canavan et al., 2016: 1, 2). There are indeed efforts that introduce bamboo species to previously non-indigenous regions. For example, over 20 bamboo species from Asia were introduced in Kenya (Lobovikov et al., 2007: 23).<sup>2</sup> Similarly, multiple non-regional species were introduced in Ghana (Ige, 2016: 5).<sup>3</sup> *Bambusa vulgaris*, meanwhile, has become considered a native species in Ghana (ibid.).

Thereby, the aggressive behaviour for which bamboo is known for, such as *Phyllostachys* bamboos (Xu et al, 2019), is the reason why i.e. South Africa only allows clumping species for commercial purposes, as monopodial species are said to become invasive (Scheba, Blanchard and Mayeki, 2017: 27). This claim, however, does not prove right as both mono- and sympodial bamboos are found to show invasive traits (Canavan et al., 2019).

As the utilisation of bamboos goes hand in hand with socio-economic purposes, bamboo plantation projects, even under the purpose of re-/afforestation, require species that grow fast and produce culms that are suitable for timber products. As is said for the example in Ghana:

*There is about 150,000 ha of forest plantations established in Ghana mainly in response to the scarcity of forest products, especially timber. With these challenges confronting the reserve forest, there is a need to supplement the forest with a more fast-growing,*

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<sup>2</sup> These species are: *Bambusa brandisii*, *B. vulgaris* var. *striata*, *B. arundinacea*, *B. tulda*, *Dendrocalamus membranaceus*, *D. strictus*, *D. brandisii*, *D. aspera*, *Oxytenanthera abyssinica*, *Phyllostachys heterocyclus* var. *pubescens* and *Thyrsostachys siamensis*

<sup>3</sup> These species are: *Bambusa vulgaris*, *Bambusa arundinacea/bambos*, *Bambusa pervariabilis*, *Bambusa vulgaris* var *vitata*, *Oxytenanthera abyssinica* and *Dendrocalamus strictus*

*regenerative, and sustainable bamboo plant to help minimise/eliminate the rate of tropical deforestation in the country. (Akwada and Akinlabi, 2018: 9, 10)*

In modern day, where the movement of market goods and the actors taking part in the market are controlled and regulated through authoritarian means, the reason for the utilisation or spread of non-native species will likely be out of economic interests. The fact that some bamboo taxa have been introduced much more widely than others is similar to the patterns observed in other plant groups, where there have been biases for species with more suitable traits for human usage (Canavan et al, 2016: 9).

#### 4.1. Example of non-ecological drivers for bamboo distribution - National Bamboo Policy of Kenya

Case in point, the variety of introduced bamboo species in Kenya is large. The National Bamboo Policy of Kenya by the Ministry of Environment and Forestry (MOEF), dated 2019, serves as an example of why non-native species spread. The policy goes as far as stating which Asian bamboo species (the same 20 as stated above) are to be introduced in Kenya, arguing they had been researched for suitability since 1986 (MOEF, 2019: 9). There is, however, no statement on what was researched in regard to these bamboo species and by whom. Moreover, at least 17 species are considered native to Africa (and another 37 if neighbouring Madagascar was included) (Ohrnberger 1999: 11), it leaves to question whether those species found consideration prior to their distant Asian counterparts.

The policy instead continues with terms of “value-addition”, “production” and “entrepreneurs”, among others (ibid.: 9, 10). Addressing the “key issues” in relation to the use of bamboo, the only issues of concern are bamboo as a product of high quality for trade and manufacturing (ibid.: 10).

Then, the policy explicitly states its goal:

*“To develop a vibrant Bamboo industry benefiting the present and future generations through sustainable management, increasing area grown with Bamboo and enabling commercialization and value-addition” (MOEF, 2019: 11).*

While the term “sustainable” finds mention, the purpose remains on manufacturing and trade, with no perspective on environmental protection.

The “guiding principles” (MOEF, 2019: 12) finally address environmental aspects, such as “quality of water resources”, “low-carbon” and “carbon sequestration”, “climate change adaptation and mitigation” and “natural forest”. Yet, even these terms are tied to socio-economic benefits of “market”, “poverty reduction”, “farmers’ income”, “products, and thereby green growth”, “product quality and market competitiveness” and so on. In a similar

fashion, the remaining policy elements continue. In essence, bamboo species are promoted in this policy on the premise of supporting environmental conservation; but the clear objective is set with economic opportunities.

While it is plausible to assume that naturally occurring species in Africa are different from, e.g., Asia's species, it may also be implausible to assume that there is no naturally occurring species in any African country with no similar attributes than those introduced on purpose. The spread of non-native species has a much more organised origin with intentions other than ecosystem restoration or conservation.

Where environmental resource conservation, biodiversity protection or disaster risk reduction is concerned, the offered policy solution may not be as "green" as it promises to be but guided by economic incentives. As it is not the task of this paper to research this phenomenon, it shall only provide an idea of where invasiveness research may be adequate.

## 5. Why bamboo is used in forest and soil reclamation

This chapter is meant to offer an overview of bamboo's characteristics which find common addressing in case studies and research articles in relation to re- and afforestation and soil regeneration.<sup>4</sup> The fast growth of the plant itself promises a revegetation of land and its underground root network promises preventing soil erosion.

### 5.1. Biomass production, re-growth and reproduction

When it comes to environmental regeneration efforts, the focus tends to be on taller bamboo species. Herbaceous or bush forms – dwarf species which grow only 10 cm high (Lobovikov, 2009: 9) – that do not reach the minimum height parameters tend not to be chosen for reclamation efforts as they cannot form a forest (Lobovikov, 2009: 7). The key term rests in the need for a “forest”, as forests are complex ecosystems that house biodiversity among plants and animals, recycle organic matter, convert soil nutrients and retain water (Aerts and Honnay, 2011). This choice also applies where no forest is required per se, as near riverbanks and on slopes. Case in point, tall-growing *Bamboos balcooa*, *Bambusa nutans* and *Bambusa tulda* were among 24 species planted in Chitwan, Nepal to restore a river bank that became eroded due to extensive logging and soil overuse from agricultural (FAO and INBAR, 2018: 45).

Tall bamboo species reach heights of 15 m to 20 m (extremes up to 40 m) and diameters of more than 30 cm (Lobovikov, 2009: 7). However, height is not the only characteristic that receives attention. Related is the already-mentioned velocity with which bamboo species can grow. Moso bamboo (*Phyllostachys pubescens*) can grow up to 1,2 m in 24 hours and 24 m in 50 days (Fu, 2001: 5). This velocity, in theory, allows for the restoration of a selected area fast, when compared to common tree planting. With maturity reached by year three or four, a fast revegetation of a landscape was observed in, for example, Ghana where *Oxytenanthera abyssinica*, *Dendrocalamus asper* and *Bambusa Textilis* were planted to bridge remnant forest patches with the aim to re-establish a coherent forest coverage (FAO and INBAR 2018: 10) or in India (Uttar Pradesh) where *Dendrocalamus strictus*, *Bambusa bambos*, *Dendrocalamus asper*, *Bambusa nutans*, *Dendrocalamus giganteus* and *Bambusa vulgaris cv striata* and Tanzania where *Bambusa balcooa*, *Bambusa tulda* and *Bambusa vulgaris* were planted to restore degraded soil (FAO and INBAR, 2018: 21, 39).

With height and fast growth, biomass develops fast. Bamboo plantations are stated to provide high or higher biomass development compared to fast growing tree species. Hermis and

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<sup>4</sup> The discussion only focusses on the biological aspects of the plant, not its socio-economic aspects. It goes without saying that socio-economic aspects will play their part in forest and soil reclamation efforts, which are especially true for bamboo and find frequent mention in FAO and INBAR (2018).

Dumago (2014: 8), for example, compared *Gigantochloa levis* grown in the Philippines and a mature plantation of *Phyllostachys pubescens* in Japan, which have an aboveground biomass of 146.8 t/ha and 137.9 t/ha respectively, compared to the fast-growing *Gmelina arborea* with 127 t/ha. To this comparison may add the by Chinese researcher often compared Eucalyptus plantation with between 112.9 and 203.8 t/ha in the region of Southern China (Du, 2015: 1771). In essence, bamboo produces a high amount of biomass at a fast rate, with an increment biomass of between 5 t/ha/year and 12 t/ha/year (Lobovikov, 2009: 26).

Three fourths of bamboo's biomass can be reached in 40 days, revealing that biomass accumulation mainly occurs in the initial growth stage (Yen, 2016). Not only does bamboo grow quickly, it also re-growths and reproduces quickly. Bamboo can be harvested after and between 3 and 7 years (depending on purpose of further use of the culms), after which it regrows by spurting new culms from the rhizome, and produces 6 to 10 t/year of new culms (Fu, 2001: 5, 6; Scheba, Blanchard and Mayeki, 2017: 1,2). Reproduction and distribution of the plant can also be achieved by separating culms with root from the rhizome and transplanting it (Fu, 2001: 5).

An important mention to make at this point is that the often-cited fast growth and reproduction rates are criticised as relying on overestimations, due to concentrating on specific plants only (Düking et al., 2009: pp. 5). Moso bamboo is such a case that tends to serve as a benchmark for the productivity of bamboo (singular) in general.

## 5.2. Carbon sequestration

A direct relation to generating biomass fast are bamboo's capacity to sequester carbon. Carbon sequestration has become an important aspect, not just from an ecological but a political aspect. Therefore, bamboo has frequently become under investigation as to how much carbon dioxide it can capture and store in the form of carbon in its biomass, and in consequence be promoted as a climate change mitigation tool (Düking, Gielis and Walter Liese, 2011; Fu, 2001; Gu et al., 2019; Hermis and Dumago, 2014; Kuehl, Henley and Lou, 2013; INBAR, 2014; van der Lugt, Trinh and King, 2018; Lobovikov et al., 2009; Lou et al., 2010; Seethalakshmi, Jijeesh, and Balagopalan, 2009).

Its biomass in general is stated to comprise of 50% carbon and is not unsimilar with trees (Jijeesh, 2009: 128, 129). This percentage alone does not position bamboos at greater importance than trees. It becomes important, however, when considering its fast growth and regeneration and that bamboo can be processed into durable wood products, which are estimated to preserve 90% of its carbon biomass (Jijeesh, 2009: 129).

The thought behind it is that harvested bamboo culms preserve more carbon than standing mature culms that enter a decay process. The continuous growth-harvest-production cycle

increases the carbon stored in an ecosystem (Kuehl, Henley and Lou, 2013: 8). Unlike trees, which are usually clear cut, cutting bamboo does not kill the plant as new culms will emerge in subsequent years and sequester additional carbon (ibid.), but instead leads to higher productivity (see Tripathi and Singh, 1994).

Research, i.e. Jijeesh (2009), Isagi (1994), Tripathi and Singh (1996) or Zhou and Jiang (2004), stated that bamboos store most of its carbon underground in its rhizomes with a ratio of about 3:1, compared to aboveground. *Phyllostachys bambusoides* stands in Japan consist of 165.1 t biomass per hectare, of which 31.7% was aboveground and 68.3% was belowground (Isagi 1994 as cited in Song et al., 2011: 420); *Phyllostachys pubescens*' biomass was 106.36 t/ha, of which 34.4 t/ha was aboveground (32.3%) and 72.2 t/ha (67.7%) belowground (0 to 60 cm of soil) (Zhou and Jiang 2004 as cited in Song et al., 2011: 420); *Dendrocalamus strictus*' biomass in the dry tropics of India accounted for 75.4 t/ha and was distributed with 23% to 28% in the vegetation aboveground, in 2% litter and 70% to 75% belowground in the soil (Tripathi and Singh, 1996 as cited in Song et al., 2011: 420). As the rhizomes survive the harvest of bamboo as well as forest fires (Kuehl, Henley and Lou, 2013: 8) they also preserve most of the sequestered carbon (Lobovikov 2009: 11).

### 5.3. Soil and water conservation

Another frequently attributed ecological benefit of bamboos is their effect to reduce soil erosion and, related, water conservation. Researching the soil anti-erodibility of forest types in Jiangsu Province, China, the results showed that Moso bamboo (*Phyllostachys pubescens*) surpassed Chinese fir trees, an Asian oak species (*Quercus acutissima*) and pine trees (*Pinus massoniana*) (Zhou and Jiang, 2004 as cited in Song et al., 2011: 421).<sup>5</sup> In terms of water conservation (canopy interception, water holding of litter layer and soil infiltration), the same comparison of species showed that *Phyllostachys pubescens* was about 30% to 45% more effective than Chinese fir (ibid.). Similar findings were made in Zhejiang Province, China, with *Phyllostachys pubescens* being about 46.7% and 57.4% more effective than *Pinus massoniana* and *Castaneam ollissima* respectively (Huang, 2010 as cited in Song et al., 2011: 421). However, here the bamboo species were about 37.2% and 16.7% less effective to conserve water than *Cycloba lanopsisglauca* and Chinese fir (ibid.).

Also in China (Anhui Province), the average surface soil runoff in bamboo forests was recorded at 0.10 m<sup>3</sup>/ha, while Chinese fir forests recorded 33% more runoff and *Pinus massoniana* forest 65% more runoff (Wu et al. 2003 as cited in Song et al., 2011: 421). The measured sediment delivery rate for *Phyllostachys pubescens* was recorded at 0.18 kg/ha,

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<sup>5</sup> *Phyllostachys pubescens*: 1.33 > Chinese fir: 0.35 > *Quercus acutissima*: -0.75 > *P. massoniana*: -0.89

while the Chinese fir forest and the *Pinus massoniana* forest showed a 57.2% and 76.4% higher rate (ibid.).

These effects can be ascribed to bamboo stands creating an extensive root and rhizome system that enhances infiltration, a thick layer of plant litter that reduces direct and splash erosion, highly elastic culms and a dense canopy to protect land from extreme winds as well as from rain fall erosion. These characteristics provide a high capacity for erosion control, soil and water conservation, landslide prevention, protection of riverbanks, and windbreak and shelterbelt potential (Kuehl, Henley and Lou, 2013: 18; Song et al., 2011: 421).

Improved soil properties by the root and rhizome system binding gravel and soil, while reducing soil bulk density, sedimentation and water runoff, was documented for the bamboo plantation project in Ghana, Tanzania, Shaanxi Province of China, Nepal as well as Colombia (FAO and INBAR 2018: 10, 21, 31,47, 58). A long-term effect of bamboo was also recorded in India (Uttar Pradesh) where over a 20-year period the ground water table rose from 40 m to 30 m deep (FAO and INBAR, 2018: 39).

By accumulating organic matter and counteracting erosion, bamboo has reversed soil degradation in exploited landscapes, regulated water flows and reduce and pollution from agricultural runoff (more examples in Lobovikov et al., 2009). In contrast, Kumari and Bhardwaj (2017) tested the effect of bamboo species *Dendrocalamus asper*, *Dendrocalamus hamiltonii*, *Bambusa tulda*, *Phyllostachys aurea*, *Dendrocalamus strictus*, *Malocana baccifera* and *Phyllostachys bambusoides* in pure plantations in India. The results showed that these bamboo species had no significant influence on soil bulk density among other conditions (ibid.: 19).

While undoubtedly bamboo plants have an effect on the soil and is superior to those species in comparison before, this fact does not exclude that having a root network at all, at a land previously stripped of vegetation, is the reason for improved ecological conditions. Other plants or trees might have achieved the same. To this caution is to add that there is no evidence that water requirement of bamboo is low. Bowyer et al. (2014: pp.8) found that farmers planting bamboo noticed that the plants require an abundance of rainfall without standing water. Even though bamboo may improve water infiltration, it may also consume the infiltrated water before reaching other soil layers or plants.

#### 5.4. Nutrient cycling

In terms of nutrient reliance to grow, research suggests that bamboo just like other plants requires specific physio-chemical soil compositions to grow, as in nitrogen, phosphorus and potassium, and therein a relatively high organic matter composition (Handique, 2014: pp. 82-95). In that sense, bamboo is not a miracle plant. Nevertheless, bamboo does grow on highly

acidic soils (pH 3.5) (ibid.: 92) and may be considered for soils that had been under heavy agricultural use.

Young bamboos (shoots) have been reported to be rich in nutrients themselves, such as protein, carbohydrates and minerals, such as magnesium, phosphorus, calcium and especially potassium (Karanja et al., 2015: 607, 609, also Tripathi and Singh, 1994: 114, 115). It may seem plausible that rich nutrients in young plants is the reason for fast growth as well as fewer nutrients being present in mature plants, if and when these nutrients spread and/or are consumed during and for growth. In any case, though these shoots may have high nutrients, they are unlikely to contribute to soil reclamation and forest growth unless shoots were inserted into the soil as an organic nutrient source themselves.

*Dendrocalamus asper*, *Dendrocalamus hamiltonii*, *Bambusa tulda*, *Phyllostachys aurea*, *Dendrocalamus strictus*, *Malocana baccifera* and *Phyllostachys bambusoides* in pure plantations in India tested for no significant influence on soil pH values and salinity (Kumari and Bhardwaj, 2017: 19).

Bamboos planted on degraded lands are indeed not very productive and require help to improve soil quality and the productivity of crops grown on the land (Kuehl, Henley and Lou 2013: 21). Tripathi and Singh (1994) experimented and documented that human intervention (harvesting) of bamboo “resulted in greater allocation (83%) of dry matter to the belowground parts, which led to the development of an extensive root system, capable of absorbing substantial amounts of water and nutrients from a soil where these are essentially limited” (ibid.: 119). But the authors confirm that this finding may be limited to *Dendrocalamus strictus*, as pertaining to their research focus.

### 5.5. Natural Resistance

Another aspect to consider is bamboos’ natural resistance to extreme situation, like fire. The in Ghana planted bamboo (*Oxytenanthera abyssinica*, *Dendrocalamus asper* and *Bambusa Textilis*) to bridge remnant forest patches were also chosen due to the region suffering from striving herdsman from the country and bordering territories who ignite bushfires (FAO and INBAR, 2018: 5). Due the rhizomes being underground, they remain unaffected by these fires and will sprout new shoots shortly after. Therefore, this underground biomass makes bamboo capable of surviving and regenerating when the biomass above ground is destroyed by fire (FAO and INBAR, 2018: 1).

## 6. Consequences when introducing bamboo to a non-native environment

With bamboos' rapid growth characteristics, apparent interest in their economic value, and research that indicates bamboo species' positive impact on revitalising soil and vegetation, it may appear obvious why bamboos were and are being moved around the world. These aspects, however, do not exclude that bamboos have no negative impact on an ecosystem. For example, *Phyllostachys* and *Bambusa* genera are known for their aggressive and invasive behaviour to spread due to their running rhizomes (Canavan et al., 2016: 11; also see Xu et al, 2019), and it has been documented that they have been introduced into a non-indigenous environment, as in Kenya (Lobovikov et al., 2007). Bamboo species like those may fit the bill of an invasive species.

Despite bamboos being moved around the world, Canavan et al. (2016) emphasised that they “are not aware of any comprehensive studies on the invasion ecology of bamboos, despite their reputation for being a group that contains highly ‘invasive’ species” and “little is known about which species have been moved where, and about the outcomes of these movements” (Canavan et al., 2016: 2, 11). *Bambusa vulgaris*, for example, has been widely distributed to 123 countries (ibid.: 11).

When little is known about the distribution of bamboos, this missing comprehension may explain contradictory arguments about the plant, such as clumping species have an acceptable to low risk of invasiveness (Dawson, Burslem, & Hulme, 2009) and running species have a higher risk of invasiveness (Buckingham, Wu, & Lou, 2013; Buckingham & Jepson, 2015), while Canavan et al. (2016) as well as Xu et al. (2019) found that both running and clumping species have become invasive.

In similar fashion, Canavan et al. (2016) also summarised that higher underground density stemming from bamboo roots and rhizomes may lead to increased surface water runoff (ibid.: 125), while FAO and INBAR (2018) found that bamboo plantations decreased runoff and increased ground water tables.

While there seems to be an indication that bamboos have the potential to become invasive, their consequences do not appear to be explicitly and comprehensively documented. The following sections are therefore a discussion repository of documented bamboo interactions with their environment.

### 6.1. Defining a species as a threat to an environment

Non-native species can cause considerable negative impacts in natural ecosystems due to the fact that these species occur in habitats where they did not evolve (Canavan et al., 2019: 119).

Depending on their adaptability and reproduction, non-native species may be considered invasive alien species.

The Convention on Biological Diversity defines an invasive alien species as species outside of their native range whose introduction and/or spread can threaten biodiversity (CBD, 2010). Such species alter the environment they were introduced to through competition, hybridisation, disease dynamics, herbivory, predation and other mechanisms (Kumschick, Alba, Hufbauer and Nentwig, 2011: 664). Other mechanisms can refer to the intervention by humans who facilitate the spread of species (see *ibid.*: 666, Table 1).

The introduction of non-native plant species may position them at an advantage in a favourable climate, in the sense that they may reproduce and grow faster than the native flora, and thereby literally outgrow the native competition. Bamboo is such a case that overwhelms other seedlings due to its competitive growth through underground expansion with little need for light (Canavan et al., 2019: 124).

## 6.2. Invasiveness of bamboo

As mentioned, the authors Kumschick, Alba, Hufbauer and Nentwig (2011) distilled mechanisms of an introduced species, which alter the environment they were introduced to. For the purpose of this paper and in the context of bamboo, the relevant mechanisms to consider are competition, hybridisation, disease dynamics and other mechanisms, such as human intervention, that may find application. Hawkins et al. (2015) created an elaborate framework on the assessment of alien taxa, providing twelve classifications of invasive mechanisms with consequences for an ecosystem. Out of these twelve mechanisms, the competition, transmission of disease, poisoning/toxicity, chemical, physical or structural impact on ecosystem, and interaction with other alien species may be considered relevant for bamboo species.<sup>6</sup>

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<sup>6</sup> Hawkins et al. (2015) distinguish between “hybridisation” and “interaction with other species” to indicate crosspollination of plants, while Kumschick, Alba, Hufbauer and Nentwig (2011) include this effect in “hybridisation”. Both mean, however, the same.

Competition refers to the species competes with natives for resources, e.g. water, space, nutrients, or light and subsequently displacing native species (Wittenberg and Cock, 2001: 17; Hawkins et al. 2015: 19).

Transmission of disease, in the sense of spreading pathogens and parasites that effect native species (Wittenberg and Cock, 2001: 17; Hawkins et al., 2015: 19).

Poisoning or toxicity refer to a species being toxic or allergenic by ingestion, inhalation or contact to wildlife, or allelopathic to plants in the surrounding (Hawkins et al., 2015: 19).

Chemical alteration of an ecosystem means that species impact on chemical dispositions (here nutrients and their cycling) and therefore soil properties, which are detrimental to native species (Wittenberg and Cock, 2001: 17, Hawkins et al., 2015: 20).

Physical or structural alteration of an ecosystem means that species impact on biotope characteristics, including light/shadow composition, physical soil characteristics and water availability (Wittenberg and Cock, 2001: 18; Hawkins et al., 2015: 20).

Interaction with other species, in particular other alien species, refers the impacts an invasive alien species has on other (alien) species by altering interdependencies, such as attracting/dispersing animal and insect species leading to altering the food web (e.g. through pollination, seed dispersal, habitat modification) (Wittenberg and Cock, 2001: 18; Hawkins et al., 2015: 20). This category may find overlap with other categories, such as competition.

### 6.2.1. Competition and interaction with other species

Interestingly, the conviction seems to be that forest systems are “generally inherently less susceptible to invasions by non-native species than most other habitats” (Canavan et al., 2019: 120). However, research papers have confirmed that young bamboo culms grow rapidly into or even above a forest’s canopy, allowing it to dominate over other vegetation (Isagi and Torii, 1997; Okutomi, Shigeyuki and Hiroko, 1996). Even when little light is available, such as in the understory of a forest, bamboos “have clear physiological adaptations that make them highly competitive in heterogeneous light environments” (Canavan et al., 2019: 124). One might say, the “root cause” for this advantage is their rhizomes, which facilitate expansion by storing and supplying energy for growth even when little light is available (ibid.). Due to this expansion, bamboos overwhelm other plants and their seedlings and quickly colonise the available space (Larpkern, Moe and Totland, 2011).

The additional capacity to produce large amounts of living and dead biomass in short periods of time may sustain dominance by suppressing the growth of adjacent plants (Canavan et al., 2019: 124). Larpkern, Moe and Totland (2011) found that seedlings of non-bamboo plants were affected in their growth by bamboo litter, while they were less affected by mixed-tree litter conditions. In summary, Yang et al., (2015) defined bamboo expansion as four stages: underground extension, aboveground sprouting, exclusive competition, and absolute dominance.

Bamboo culms' fast growth rates aboveground in combination with their rhizomes fast clonal reproduction belowground may be considered an advantage in reclamation projects, where vegetation coverage is required to stabilise or improve soil conditions or connect isolated vegetation. However, this fast spread may also be the prime reason for bamboos as being considered invasive, in particular in non-native environments. Due to this fast growth, it can be expected that bamboos are more successful in competing for resources of light, water, nutrients and space itself, and consequently impact on surrounding plants vegetation.

### 6.2.2. Physical or structural alteration

Bamboos' characteristics for competitiveness and interaction with other vegetation indicate alterations of the ecological environment. A visible alteration is the bespoken dominance in vegetation. As bamboos form dense stands, this can result in the exclusion of native species (as in Larpkern, Moe and Totland, 2011; Okutomi et al. 1996). Subsequently, the aboveground composition, as within and of forests, can change from a variety of plant stories with different leave compositions to a dense, homogeneous bamboo culm dominated landscape (Kobayashi, Saito and Hori 1999).

The different composition aboveground was found to have consequences on water infiltration and runoff. Where bamboo was the dominant plant, as in bamboo forests, the canopy comprises of bamboo leaves only and the understory becomes very scarce in plant variety (Ide et al., 2010: 81). This circumstance has been observed to lead to less rain water interception by bamboo canopy, comparing *Phyllostachys makinoi* and betelnut and Chinese fir (Lu et al., 2007). Also, as the soil becomes covered by bamboo leaf litter, which is plentiful corresponding to plentiful growing culms, it leaves to investigate whether the predominance of bamboo with relatively less rain interception compared to broadleaf trees and plants has negative effects on rain water percolation. In fact, bamboos can lead to changes in hydrological processes in the soil in the sense that they increase water content (Shinohara & Otsuki, 2015). While such an effect by itself is a positive one, where water tends to be scarce and run off quickly, it leaves to wonder whether other vegetation can cope with increased soil moisture.

As bamboos alter structure above- and belowground, they can have the contrary effect of what was expected. Dura and Hiura (2006) concluded in their observation of bamboo stand expansion and the relation to sediment disasters that the increase in bamboo vegetation on slopes also increased slope failures, due to developing a dense root mat in the upper soil. This would indicate that the dense root system of bamboos is not suited on slopes per se. Then there is the potential that fast growth and expansion of bamboo biomass can support sequestering carbon above- and belowground. However, where bamboo is being promoted

for its ability to sequester carbon, it should be compared to the existing potential offered by the natural vegetation, in particular existing non-bamboo forests. Shifts in vegetation structure and function due to bamboo encroachment into evergreen broadleaved forests appears to lead to increased carbon dioxide emissions, as former forest carbon stocks decline through replacement of bamboo stands (Bai et al., 2016; Xu et al., 2020).

Finally, the same natural resistance to extreme situations bamboo is praised for can be a concern when naturally occurring interventions, e.g. hurricanes, frost or fires, cannot decimate bamboos in regions where their native counterparts have been decimated. As they are resilient to damage due to their underground rhizomes, eradicating bamboo would require removing the entire clumps, which would cause further damage to soils, trigger pollution, and kill native vegetation (Blundell, et al., 2003: 17). In other words, structural soil and vegetation conditions are influenced by its physiological properties to resist environmental influences (Okutomi, Shigeyuki and Hiroko, 1996: 726).

### 6.2.3. Chemical and nutrient alteration

With an invasion of bamboo species replacing former plant variety (if any) as well as altered light and soil density conditions, changes of the nutrient and therein chemical composition of the soil can also be expected to change.

An influence on the chemical and nutrient properties may stem from bamboos' leaf litter. Handique (2014) reported an increase of soil organic matter in bamboo dominated forest from leaf litter. This litter would act "as mulching material promoting good infiltration and thus resulting in high amount of nitrogen, phosphorous and potash status of the soil" (ibid.: 93). A high(er) leaf litter may influence the chemical and nutrient cycle positively.

In contrast, Canavan et al. (2019) and Veblen (1982) suggest that the build-up of leaf litter on the top surface slows the rate of decomposition of organic matter and, therefore, be deleterious for nutrient cycling.

Influential to this slowdown of decomposition, Veblen (1982) reported the accumulation of silica from bamboo leaf litter. In relation, Ikegami et al. (2014) concluded in their comparative study of forests that the bamboo forest had a significantly higher silica content than an evergreen broad-leafed and a coniferous forest. However, silica contents in soil increase nutrient availability in soils and uptake in plants (Greger, Landberg and Vasilik, 2018). This should mean that other plants also benefit from increased bamboo leaf litter.

It appears that the increase of leaf litter reduces or inhibits the grows of other plants that could have benefitted from the silica. Bai et al. (2013) compared plant species richness with and without bamboo presence. The authors found that herbs are more often present in needle and broad-leaved forests mixed with bamboos, and that the removal of bamboos increased plant

species in the shrub layers (ibid.: 294). Bai et al. (2016) and Song et al. (2016) further identified a reduction of nitrogen in forests where bamboo encroached upon.

Lima et al. (2012) surveyed Brazilian Atlantic Forest soil regarding its composition. Within bamboo areas, the soil was significantly richer in potassium and magnesium. Also, the bamboo areas had lower potential acidity and aluminium saturation. Taken together, the authors concluded that bamboo's soils are chemically more fertile (ibid.: 35). This conclusion, however, is based on one survey. It only means that it is the present condition; it is not exclusive of the soil properties having existed before the introduction of bamboo, or whether this is the needed composition to grow bamboo. It cannot indicate whether bamboos caused this composition. The soil in question was also predominantly clayey, while in non-bamboo plots soil was sandy. The authors acknowledge that the higher soil fertility was probably driven by the more clayey texture of soils under bamboo plots (ibid.: 36), and thus may not be attributed to bamboo at all.

While this seems to be an understudied topic, there may be a link between the amount of leaf litter from bamboo and the plant variety and, subsequently, the nutrient cycling. It should be noted, though, that statements about high amounts of leaf litter covering soil tend to derive from areas where winter periods (frost) affect litter production. Whether similar amounts of leaf litter by bamboo are produced under evergreen topical conditions, also requires further insight. In any case, whether bamboos improve or deteriorate chemical and nutrient composition of the soil, either condition can expect a change in the abundance of bacterial, other microbial and insect life (Canavan et al., 2019: 125).

#### 6.2.4. Disease transmission

Invasive species have the potential to be a host for pathogens, with every species potentially modifying the existing structure and function of ecosystems and the ecosystem services (Crowl, et al., 2008: 243). Xu et al. (2007) found 208 pathogens (including fungi, bacteria, mites, virus and others) associated to 148 bamboo species in China alone. One might expect a high potential for spreading disease by introducing alien bamboo species. Indeed, the Bamboo mosaic virus has been found to be a major threat to bamboo species and to be easily transmitted from one plant to another by means of insects (Chang et al., 2017).

Contrary to expectation, there does not seem to be research on bamboos spreading disease onto other plant or animal species, unless it exists in languages other than are at my disposal. Despite the over 200 pathogens affecting bamboo itself, there appear to be only reports on bamboos' own susceptibility to pests (FAO and INBAR, 2016: pp.16). It leaves to wonder whether bamboos' 183 fungi (Xu et al., 2007) do not affect other species.

It appears more reasonable to expect that introduced bamboo species can facilitate the spread of a disease that, like the host, is non-native to its environment and potentially at an advantage, since Prospero and Clearly (2017) highlighted the escalating rate of exotic pathogen species introductions affecting forest trees in North America and Europe (ibid.: 1).

#### 6.2.5. Poisoning or toxicity

In terms of being poisonous or toxic towards other species, plant and animals, there appears to be no traceable study that would indicate any such finding. One might speculate that an overconsumption of bamboo leaves may lead to indigestion among herbivores, which are not used to consuming bamboo. On the other hand, it is widely known that certain animals consume bamboo almost exclusively, such as the giant panda. Furthermore, bamboo shoots contain high proteins, amino acids, carbohydrates, many important minerals, and vitamins (Nongdam and Tikendra, 2014), which makes it an important food source even for humans.

### 6.3. Cascading consequences for biodiversity

The invasiveness of bamboos and its direct mechanisms have been discussed above. Separately taken, the introduction of bamboo has consequences for soil properties, water percolation, nutrient cycling and vegetation competition, among others. These individual consequences create a scenario that can threaten the functioning of an entire ecosystem, thus creating consequences of the consequences.

Ecosystem functioning is affected from altered ecological conditions, such as water infiltration, soil erosion, nutrient cycles and finally the food web (Wittenberg and Cock, 2001: 18). The disturbance of an ecosystem may have cascading effects and cause extinctions (ibid.) In other words, given the impact bamboo can have on a habitat, bamboo may have the potential to reduce biodiversity.

Biodiversity can be interpreted differently. Leaning on Elzinga (2001), Zhang et al. (2012), Willig and Presly (2018) and the Convention on Biological Diversity (1992), biodiversity can be understood as the biological variability within and between life forms of a location, an ecosystem or a landscape. Biodiversity can be understood as diversity within species, between species and the diversity of ecosystems.

Biodiversity is defined and measured as a property, which in turn consists of two primary components: species richness and species evenness. Species **richness** refers to the countable number of species in a given area and “does not consider differences in species relative abundance” (Zhang et al., 2012: 1). Species **evenness** refers to the similarity in species’ relative abundance in a given area (ibid.) Species richness and evenness can vary with change in key ecological processes such as competition, predation, and succession, each of which can alter proportional diversity (ibid.). This circumstance leads to another measure for biodiversity and is expressed as the **difference** between richness and evenness (ibid.; Purvis and Hector, 2000).

### 6.3.1. Bamboo facilitates plant biodiversity loss

As bamboo species have been discussed to outgrow its competition, even under low light conditions, and to repress the growth of neighbouring plant species due to litter production and extensively growing root networks, with consequences for physical-chemical soil properties, they have been found to impact on biodiversity negatively. The formation of dense stands can result in a decline in biodiversity through the spatial exclusion of native species in an area.

Okutomi et al. (1996) explored the cause for the replacement of previous broad-leaved forests with bamboo forests (*Phyllostachys pubescens*). Despite considering the possibility of human intervention having led to the dominance of bamboo, the authors came to the conclusion that the bamboo species systematically encroached upon the previous mixed forest. The rhizomes, leaf litter, culm density and canopy did not allow other plants to vitalise, which eventually died off (ibid.: 726) Suzaki and Nakatsubo (2001) similarly found that total number of plant species (species richness) increased in those bamboo stands (*Phyllostachys bambusoides*), where culms had a lesser density, allowing for more light and space.

In other cases, bamboos were found to decrease overall plant biomass or carbon storage as well as tree density (Lima et al., 2012; Bai et al., 2013).<sup>7</sup> More studies (Kudo et al., 2012; Tao, Shi and Wang 2012; Zhang and Cao, 1995) similarly confirmed the presence of bamboo reducing plant diversity of shrub and herbaceous layers.

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<sup>7</sup> To note is that the reduction of biomass/carbon refers to standing stock. As Xu et al. (2020) point out: “the annual biomass yield per ha for moso bamboo is high compared to other subtropical forest species” (ibid.: 3). The fast regrowth of bamboo species, if and when culms are harvested and processed into durable products, may counter balance the lower standing biomass. “Standing biomass is generally higher for an original forest compared to bamboo, but biomass yield calculated annually is greater due to biennial bamboo timber harvests.” (ibid.)

Finally, Larpkern, Moe and Totland (2011) explicitly measured bamboos' (*Bambusa tulda* and *Cephalostachyum pergracile*) biodiversity impact. The authors concluded that seedling species richness was lower under bamboo canopy, compared to tree canopy (ibid.: 164). Seedling abundance was also affected negatively by the prevalence of bamboo (ibid.: 165). The same trend of downwardness for species richness and evenness was tested and confirmed by Yang et al. (2010), stating that *Phyllostachys pubescens* led to “gradual simplification of the hierarchy and the significant change of species composition” (ibid.: 553).

### 6.3.2. Anthropogenically accelerated biodiversity loss

Canavan et al. (2019) assessed the impacts of recorded bamboo invasion in temperate and tropical forests. The authors found that the impacts were “similar in the native and non-native ranges of weedy bamboos” (ibid.: 121). In other words, it makes no difference to bamboo whether they grow in their indigenous environment or not. The authors noted in particular that the impact of bamboos on other plant species was augmented due to being “a response to human-mediated land transformation and disturbance of forests” (ibid.). With the example of Moso bamboo, this species has become increasingly problematic, because of the increased demand for bamboo products. This has led to mixed-species forests being converted to bamboo monocultures (ibid.: 122, 123).

The reduction of species diversity facilitated through human intervention was confirmed by Lou and Henley (2010), which reviewed bamboo management techniques that led to declines in plant diversity in bamboo forests and ultimately established bamboo monoculture plantations in its stead (ibid.: pp.11). While bamboo species themselves already have a direct impact on their natural surroundings, the intensive management of bamboo forests additionally “simplify the structure of the forest and decrease the species richness and biological diversity of the tree, shrub, and herb layers” (Song et al., 2011: 424).

### 6.3.3. Chain reactions in and from biodiversity loss

With an impact on reduced diversity among other plant species, the diversity of other ecosystem elements can be threatened. When bamboo dominates or replaces native plants, it impacts on those living off these plants: such as birds or insects, and herbivores in particular, and predators that depend on herbivores. For example, bamboo monoculture forests in Hunan and Sichuan Province of China were found to have lower avian diversity compared to nearby mixed forests (see Lou and Henley, 2010). The removal of bamboo biomass along river banks in Japan led to increased biodiversity (Suzaki and Nakatsubo, 2001).

The loss of plant diversity caused by bamboo, may trigger a chain reaction that leads to the loss of other species of higher order; in particular, when rare key species become affected.

Upsetting ecological balances and interactions, as in flowering processes, affects pollinators survival and trickles down to the prey populations to the point where they can no longer cope with natural predation rates (Wittenberg and Cock, 2001: 17). Losing rare species reduces “the functional richness, specialization, and originality of assemblages more than expected under a random loss of species” (Leitão et al., 2016: 5). This leads to a loss of refined interactions among species, an eradication of highly specialized forms of resource utilization and an undermining of important ecological processes (ibid.).

To such refined interaction also count microbial activities, such as fungi and bacteria. A study in Zhejiang and Fujian Province documented declines in soil fungi and bacteria diversity (by 45% and 90%) in bamboo monoculture forests over an eleven-year period (Lou and Henley, 2010: 12). The loss of biodiversity appears to have increased susceptibility to pest attacks, as found with mite infestation among bamboo monocultures compared to mixed forests (see Zhang et al., 2000).

Nevertheless, other cases depicted a positive relation between bamboo plantation and biodiversity. Planted bamboo in Chitwan, Nepal allowed other plant species to regenerate (FAO and INBAR, 2018: 47). Sanchez and Camargo (2012) recorded higher numbers of bird species where bamboo-present forest areas. And Cairo-Cairo et al. (2017) showed a regeneration of “macrofauna” along riverbanks in Cuba.<sup>8</sup>

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<sup>8</sup> The authors did not clarify what species they meant with macrofauna.

## 7. Bamboo in soil and forest reclamation – does it pose a threat?

A lot of English-speaking literature on bamboo seem to either originate from China or Japan or from projects located in China or Japan (forests, plantations). There is also a wealth of Chinese speaking literature on bamboo research, which is unfortunately not accessible to myself and non-Mandarin speakers. Most studies drawing conclusions on bamboo's repercussions may therefore be too centric on bamboos growing in the environment of geographic and climate of China and Japan, especially when discussing *Phyllostachys pubescens* (Moso bamboo).

Then again, research on Moso bamboo is not irrelevant, it represents 70% of bamboo resources in China alone and is being extensively planted (Lobovikov et al., 2007: 13, 15), and China is a vast geographical region that spans different climate zones and varying topographic characteristics, where bamboo can grow.

Most incorporated case study and research references in this paper referred to impacts of bamboo in and on forests, and occasional riparian settings. Given the intent to review the impact of bamboo on forests and soil reclamation, non-forest settings have come too short due to literature on and around bamboo seemingly predominantly discussing forest. Interestingly, Canavan et al. (2019) claimed that forest systems were less studied in invasion science than other major habitats, such as grasslands (ibid.: 120). If that was true, it appears to be the opposite in the context of bamboo.

The underrepresentation of bamboo impacts in non-forest settings (e.g. grassland meadows or barren lands) may be an important finding by itself, as it would indicate that ecosystem settings other than forests in the context of bamboo expansion are understudied, with exceptions provided by Kudo et al. (2011, 2017) on alpine snow meadows in Japan, the Nepal case study in (FAO and INBAR, 2018: 47) on recovery of riverbanks as well as the Cairo-Cairo et al. (2017) research paper also on riverbanks in Cuba. Going into the references lists from those authors, it is noticeable that their sources also reference almost exclusively forest conditions as comparison for biodiversity.

Despite bamboo being transported around the world, research seems to be primarily centred in China and Japan, as opposed to research on species from China and Japan in non-native environments, such as Africa. In their comprehensive review on the impacts of bamboos, Canavan et al. (2019) stressed the limited research about bamboo and insufficient knowledge available (ibid.: 125). Other comprehensive and critical review on bamboo research was carried out by Bowyer et al. (2014) and Scheba, Blanchard and Mayeki (2017), which also tended to cite research from Asia, such as China, Japan and India.

The specific characteristics of bamboo and the resulting consequences, as far as identified, indicate negative effects in nature reclamation efforts due to bamboo's weedy growth and competition suppression behaviour. However, case studies by FAO and INBAR (2018) as well as interviews conducted by Scheba, Blanchard and Mayeki (2017) mention that weeding is necessary to protect the planted bamboo from being overgrown in its earlier stages by other plants (FAO and INBAR, 2018: pp.6; Scheba, Blanchard and Mayeki, 2017: pp.21). There is also "no consensus on the optimal growing conditions of bamboo" with regards to nutrients and water requirements (Scheba, Blanchard and Mayeki, 2017: 34). Soil conditions exist where bamboo does not grow, and "extensive soil tests (chemical and physical), research and trials indicate no difference in soil properties" why bamboo did not grow in specific areas (FAO and INBAR, 2018: 18). In other words, bamboos *might* not grow anywhere by itself and in consequence be less of an invasive risk.

Bamboo appears to have negative effects on certain ecosystems, but it will depend on the environmental setting and the intended aim (e.g. biomass regeneration vs. soil regeneration) as well as the species used. The latter will require individual study on their behaviour. Although in species of e.g. the popular Moso bamboo, predictions are likely about suppressing diversity. Moso bamboo gradually decreased biodiversity and threatened other species, especially for some rare and endangered species, and this is an increasing concern (see Song et al., 2011).

Being a threat to diversity stands in contrast to bamboo plants being found to raise groundwater levels, increase land productivity and improve micro-climates (see Singh et al. 2013). Bamboo being a threat to biodiversity on barren, degraded lands might not be the case. When the land has been degraded to a degree where no species grows, bamboo is hardly a competitor or disease distributor. When the soil cannot carry vegetation anymore due to nutrient overconsumption from previous land use or chemical composition being unfavourable, bamboo might at worst be an alternative to desertification. In vegetation-degraded environments, as exemplified in Africa by FAO and INBAR (2018) bamboo can indeed improve conditions. The question remains whether native species, other than bamboo, would achieve the same.

An argument for whether bamboo becomes invasive in reclamation efforts due to its growth characteristics comes with the "lag phase", as described in the process of invasion (Crooks, 2005). Introduced species can exist in low numbers for extensive periods of time (lag phase) before expanding rapidly in the so-called explosion phase, and notable impacts become visible or influential long after the onset of invasion (Crooks, 2005: 316; Hawkins et al., 2015: 1361). As has been reported that bamboo flowering can take place biennial or in over a 100 years' time for all local species at the same time (Janzen, 1976), flowering of bamboo leads to mass spreading of seeds and thus propagates it explosively.

As there have been cases identified where bamboo contributed positively to vegetation and diversity, vilifying bamboo as detrimental to ecosystem restoration efforts may be too hasty. The extent to which introduced bamboo species have consequences on their surroundings will greatly depend on the purpose of the introduction and the accompanied management of the plant. As it stands, it appears that bamboo has more often than not negative consequences for mixed forests, while bamboo can bring about positive consequences in areas where vegetation is lacking. If and when bamboo is introduced for the purpose of forest and/or soil restoration, considerations should go into native alternatives, including native bamboos. As there are tendentially socio-economic benefits associated with planting bamboo (See Song et al., 2011), those benefits may outweigh those alternative considerations.

## 8. Conclusion

The conclusion to this paper, ironically, was already formulated by Xu et al. (2007) more than a decade ago and apparently remains yet to be addressed by research.

*“[A]vailable literature also includes inconsistent findings regarding biological diversity and many soil processes, which probably reflect complex interacting factors including original forest composition, other soil properties, and invasion history. Therefore, additional long-term studies on the sustainable development of bamboo and its effect on soil ecology are needed. Additionally, these studies should explore optimum ratios of bamboo area to total forest area so as to minimize threats to biodiversity, both above and below ground.”* (Xu et al., 2007: 6)

Relevant findings in the context of forest and soil reclamation show opposite impacts. While previous non-bamboo forests seem to be affected negatively by the introduction of bamboo and see their biological diversity and biomass declined, non-forest areas seem to benefit from it by providing biomass to attract or allow for other life forms, including vegetative competition. The difference of findings in this paper is suggested to rest in whether the focus is on establishing a vegetative ground cover or whether an existing vegetative ground cover is disturbed through the presence of bamboo. Therefore, research and discussions on bamboo will have to distinguish into the environmental settings in which bamboo grows, what these settings were before bamboo was introduced and what the original purpose for the introduction of bamboo was.

As bamboos provide an annual supply of woody biomass, using bamboos instead of trees for individual or large-scale manufacturing can reduce pressure on other woody forest resources and help avoid deforestation. From this perspective, bamboo can contribute simultaneously to adaptation and mitigation of climate change (Akwada and Akinlabi, 2018: 1; Kuehl, Henley

and Lou 2013, 2013: 22). In that context, bamboos might be better understood as a helping tool in landscape restoration than a miracle plant due to its potential side effects.

At last, it must be noted, as this paper developed, it became apparent that little to no studies make bamboo the research focus as an invasive *alien* species. While there are literature acknowledgements of bamboo being invasive, the intended discussion on bamboos' directly observed consequences in non-native environments fell relatively shorter than expected due to studies being limited in geographical scope. Many studies that discuss bamboo as invasive discuss it for environments of the same geographical region and climate; in the sense of being non-native to specific, local habitats that exists in the same geographical region. This personal observation explains why Canavan et al. (2016) stated that there are no comprehensive studies on the invasion ecology of bamboos.

This lack of comprehensive studies may also be underpinned by the many bamboo species that grow on almost every continent, and in consequence may have blurred the line between distinguishing into invasive individual bamboo species (plural) and bamboo as a (singular) genus. The latter shortcoming may require paying closer attention to whether research and advocacy discusses the impact or benefits of Bamboo (genus) or bamboos (species – plural). As it has been difficult in this paper to find a balance between discussing bamboo (singular, genus) and bamboos (plural, species), this conceptual problem may be interfering with providing accurate information about this plant.

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