Understanding the risks of an emerging global market for cultivating bamboo: considerations for a more responsible dissemination of alien bamboos

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Introduction

In the past decade there has been a fast emerging culture surrounding bamboo's potential in mediating environmental concerns and satisfying social and economic qualms. Modern processing techniques have enabled bamboos to be transformed into an array of products that in many ways outcompete traditional wood products in both production cost and product quality. Other enticing benefits include environmental mitigation by-products such as carbon sequestration, soil stabilisation and restoration of degraded lands. This has resulted in a strong drive for bamboos to be cultivated en masse around the world (Lobovikov 2005). Media efforts have particularly driven this movement by somewhat sensationalising bamboos potential with promising titles such as 'miracle crop' and 'wonder plant'. Although there seems to be a compelling economic case for the possibilities of bamboo; most research on bamboo has focused on agricultural potential, maximising yields and on the economic valuation of the industry. Few studies have addressed the environmental risks associated with mass distribution and propagation of non-native species of bamboo. Caution should be exercised in cultivating bamboo species in new ranges if a more responsible and sustainable industry is sought. In this paper, we will make a case for why further research is needed to anticipate invasion risks.

Bamboo and Invasion Ecology

Globalisation has intensified the spread of non-native species through the mass movement of humans and biological material (Meyerson & Mooney, 2007). This has resulted in a reshuffling of the world's biota at an accelerated rate which is causing substantial ecological, social and economic impacts (Bardsley & Edwards-Jones, 2006; Simberloff *et al*., 2012). Invasive alien species are one of the greatest threats to biodiversity worldwide and affect ecosystem services and functions (Wilcove *et al*., 1998; Cook *et al*., 2007). It is increasingly recognised that if pre-emptive measures are to be taken to reduce future threats then the mechanisms and drivers that facilitate invasions need to be understood. One way to better comprehend the inherent complexity of the process of invasion is to dissect the events into stages (Forsyth et al. 2004). Figure 1 conceptualises these stages of invasion, the possible outcomes, and the determinants that may enable invasion success in the case for intentional introductions of cultivated plants.

For a species to be introduced, establish, spread and invade, a number of barriers must be overcome. The first stage of invasion generally requires an economic reason for a species to be cultivated, leading to the beginning stage of the continuum, the **introduction** of a species to a new range. Usually species that are **climatically suitable** will be more likely to be introduced to a similar climatic region (Forsyth et al. 2004). In the case of bamboos, this has been true, where temperate species from Japan and China have been most commonly introduced due to the milder climates in Europe. Additionally, there has been a historical context of trade between these two regions further promoting Asian species. The origin of these introductions partially stem from the Victorian plant hunters in the 18th-19th century, bamboos were seen as an exotic novelty and became a popular household ornamental (Townsend 2013). From Europe it is likely that these introduced species were further exported around the world, especially to other Commonwealth countries such as Australia (Cook and Dias 2006) Figure 2 shows maps of the native and introduced ranges of bamboos, where darker shaded regions indicate a higher count of species; many species have been introduced to Europe, the United States, and Australia. Overall about 18% (150 species) of bamboo species have managed to overcome the introduction barrier by being transported outside of their native range.

After a species has been introduced in the initial stage (Figure 1), with the aid of certain **dispersal** and **reproductive traits**, a population may escape and spread away from the original site of introduction. This emphasises the importance of understanding the purpose for introduction as this may dictate which species and which traits are being selected enabling escape. Historical bamboo introductions probably favoured aesthetic merits, such as colour and striation on culms and leaves if the primary reason was for ornamental purposes. But what makes bamboo a particularly interesting plant group to study is the array of uses and reasons for which it may be introduced. It is only recently that bamboo species have been introduced for cultivation purposes. It is also important to note that cultivation of bamboos in itself is not an emerging notion. Bamboos have had a long and important history in Asian culture, and to a degree in parts of South America, where there are many native species. However, the movement to mass cultivate bamboo in North America, Africa, Europe and even Australia is a far more recent endeavour. This has likely resulted in shift of the species of interest over the last century, as different species may offer different merits depending on the purpose. For example, 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. But unfortunately traits such as fast-growth rates may also be 'weedy' traits, which may facilitate **cultivation escape** on the continuum (Figure 1).

In many island nations where bamboo species were introduced for wood production, there have been many cases of populations escaping cultivation and naturalising. In Puerto Rico the Asian species *Bambusa vulgaris, B. longispiculata B. tulda, B. tuldoides* and *Dendrocalamus strictus* were introduced to the Caribbean National Forest in the 1930s and 1940s for stabilising slopes (O'Connor *et al.,* 2000). They have since naturalised around waterways in riparian areas and have been spreading through vegetative means of rhizome networks (O'Connor *et al.,* 2000). Naturalised populations can continue to become **invasive** depending on a number of determinants, such as **residence time** of introduction, or the duration or time the species has had to establish. If a species does become invasive there can be a number of outcomes with regards to the impacts it may impose on social, economic and ecological systems.

Certain species of bamboo, particularly taxa in the genus *Phyllostachys*, have been reported as noxious weeds in both native and non-native ranges (Chang and Chiu 2015, Xu et al. 2015). This is attributed to the ability of woody bamboos to form fast growing monoculture forests that displace surrounding vegetation, which is detrimental to local biodiversity (O'Connor *et al.,* 2000). In southern China, the native species *Phyllostachys edulis* (Moso bamboo) is widely cultivated and has spread rapidly in certain areas, outcompeting with tree species. The advancement of bamboo mono-forests into mixed forests has caused substantial impacts on plant diversity and community structure (Xu et al. 2015). This has been observed in Tianmu Mountain Nature Reserve where there has been growing spread of bamboo; Bird diversity was observed to be one-seventh of that in evergreen broadleaved forests (Yang *et al.,* 2008). An 11-year study in the Chejiang and Fuijian forests looked at the effects of monoculture bamboo forests for agricultural purposes. It showed a substantial decline in fungi, bacteria, grass and shrub diversity (He and Lou, 1999). So overall in China the high demand for bamboo has likely facilitated the increased advancement of bamboos replacing mixed forests. These native bamboos, such as *Phyllostachys edulis*, have exhibited weedy behaviour that are associated with a substantial decline in biodiversity. In Japan, *Phyllostachys edulis* was introduced in the 1700s and has been widely cultivated. However, in the 1980s a decline in the bamboo industry led to plantation sites being abandoned. Without management this facilitated a spread of bamboos into neighbouring forests, leading to bamboo becoming dominant (Fukushima et al. 2015). Similar, to impacts in the native range of China, the monocultures of bamboo were observed to transform these ecosystems, and in general negatively impact diversity (Chang and Chiu 2015).

The above examples provide insights on how extensive cultivation, leading to high or high propagule pressure, can give more opportunities for a population to overcome barriers along the introduction-invasion continuum (Lockwood et al. 2005) An emerging insight is that past biological invasions can provide important models for how particular plant groups might be expected to invade and cause impacts. Past outcomes and impacts, such as those observed in the *Phyllostachys* genus should be seriously considered when promoting bamboo in new ranges, especially where there are conservation concerns. However in the case of bamboos, the natural invasion experiment is incomplete meaning that the full potential of all species is undetermined. Although bamboos have been extensively introduced around the world, there has been a bias for temperate Asian species. It is possible that South American species, for example, may have more weedy potential than is currently evident, but these species may not have had the same opportunities to invade as temperate Asiatic species have. Secondly, it is possible that the reasons for introductions, and thus the selection of bamboo species, has changed -from a preference for ornamental traits to a preference for fast-growing and more resilient species, or 'weedier' bamboos. Thus, the full potential of bamboos as weed has not been expressed, and there might be a poor relationship between fundamental traits favouring invasions and current levels of invasions.

Suggestions and considerations

There are a number of considerations that should be made when making a case for bamboo cultivation. As bamboos are weak seed producers, due to infrequent and extended times between inflorescence, spread is mainly through rhizomal growth. Selection of planting sites should consider adjacent land use. Close access to water ways and ecologically sensitive areas should be avoided, to reduce the risk of bamboo spreading into these pathways. A long-term plan and future management of cultivation sites should be established, to minimise abandoned bamboo plots, as bamboo invasions can potential cause significant impacts.

One of the main motivations for bamboo cultivation is that it could present a more 'sustainable' option to current forestry practices. However, Sustainability is the marriage between economic, social, political and ecological systems over an extended time period (Brown et al. 1987). If the species introduced for cultivation have detrimental impacts on native flora and fauna this would not be in harmony with the ecological aspect of sustainability, and should be reconsidered. For a more responsible and 'sustainable' industry for bamboo we need to know more about the weed potential (or invasiveness) of different species is, and also have better methods to reduce escape from cultivation. More efforts should be made to select for species that have low invasiveness to optimize both economic and ecological benefits. In summary, mediating climate change concerns with 'wonder plants' that seem to offer simple solutions to complex problems, should not supersede the risks of invasions. The damages in the long-term from invasive non-native species could be greater than the original concern.

Figures

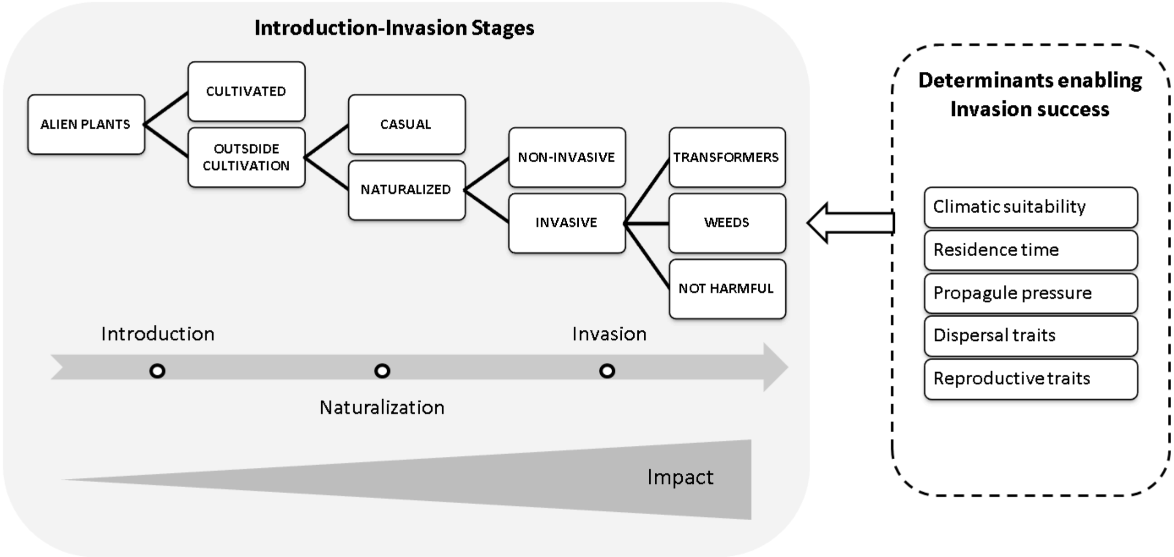

Fig 1. Conceptual diagram of the stages and determinants of plant invasions based on combined information from (Pysek et al. 2004) & (Blackburn et al. 2011).

Fig 2. The native and introduced range of bamboo species. There are 1,404 species of bamboo, 150 of which have been moved outside their native ranges. Data are from numerous sources, mainly Kew's GrassBase and the Global Biodiversity Information Facility.

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