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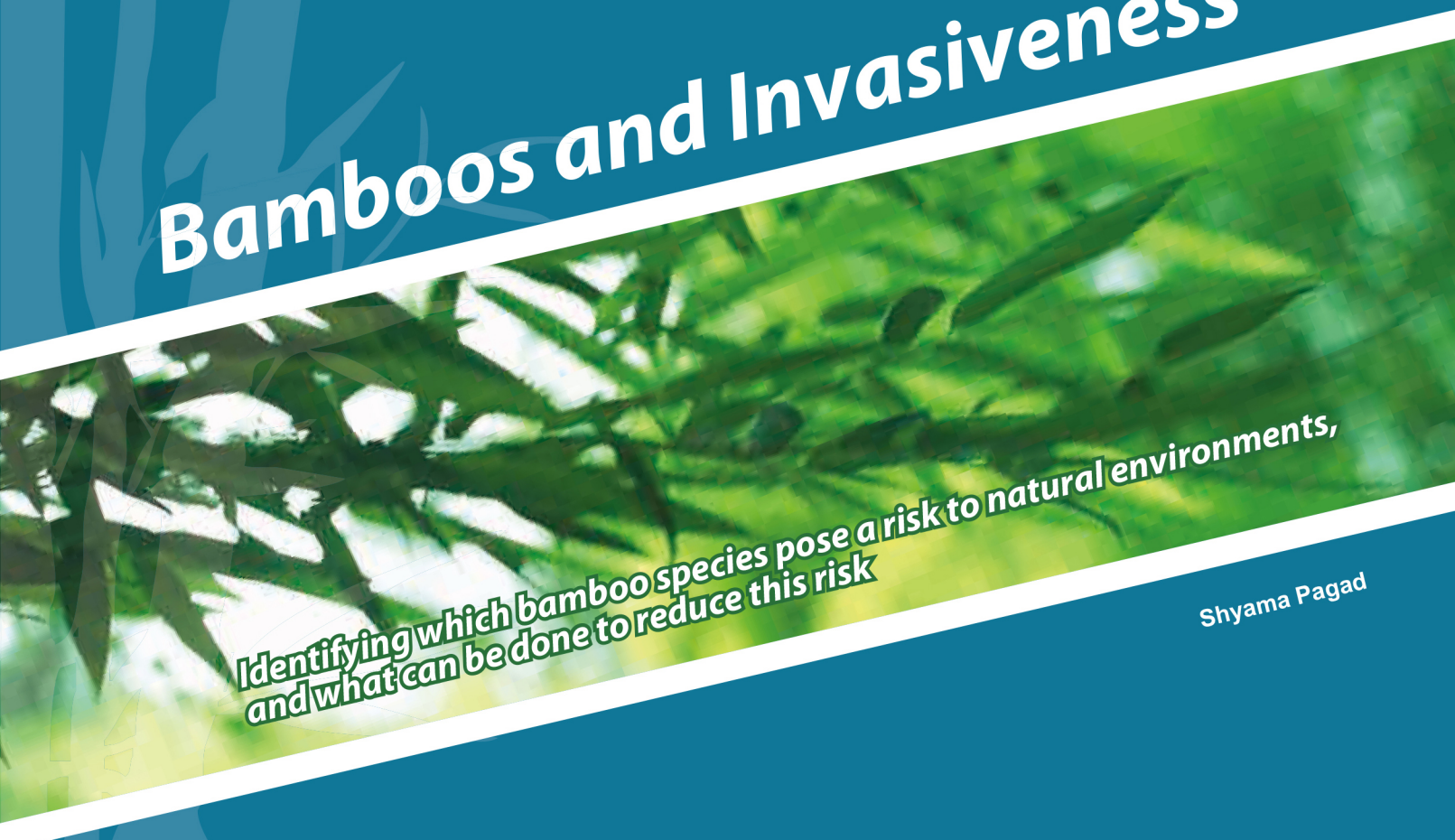
Bamboos and Invasiveness



Identifying which bamboo species pose a risk to natural environments, and what can be done to reduce this risk

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INTERNATIONAL NETWORK
FOR BAMBOO & RATTAN

IUCN
SPECIES SURVIVAL COMMISSION
ISSG
Invasive Species
Specialist Group

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About INBAR Working Papers

INBAR Working Papers detail and provide analysis of on-going research on bamboo and rattan. These are living documents that may be updated in the future based on further research and developments.

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Contents

Key messages

- Invasive species are recognized as one of the five most important direct drivers of biodiversity loss and change in ecosystem services – alongside habitat change, climate change, over-exploitation of species, and pollution.
- Bamboo species have been widely introduced outside their native range – most often intentionally, for economically beneficial purposes such as forestry, timber production, erosion control, landscape improvement, and agriculture.
- Although some bamboo species are known to be invasive, particularly 'running' bamboo species, which exhibit vigorous growth and have been known to invade natural and semi-natural areas, many are not invasive and pose no threat to natural environments.
- By avoiding invasive bamboo species through a robust assessment of risks and the introduction of sensible forestry management practices, countries can enjoy the full benefits of this strategic resource, reaping its many benefits for sustainable development.
- When early detection and containments fails, proven manual, physical and chemical options are available.

Executive summary

Bamboo is a vast strategic resource that countries in the world's tropical and sub-tropical regions can use to better-manage climate change, provide beneficial ecosystem services, and new income sources for rural populations.

Yet, when the topic of bamboo is discussed, the issue of invasiveness often arises. The short answer to this question is that there are some 1600 different bamboo species with a variety of characteristics. While some of these are known to be invasive, particularly 'running' bamboos, many pose no threat.

Assessing risks and preventing the introduction of invasive and potentially invasive bamboo species is the first line of defense. But, even in situations where invasive species are present, the risk posed to the environment can be substantially reduced through effective management strategies: proven manual, physical, and chemical options.

This study identifies the bamboo species known to pose a risk and the strategies that countries can adopt to mitigate this risk. Information was gathered through a comprehensive literature review and consultations with bamboo experts worldwide. The result is a practical resource that offers countries useful information on best practices and lessons learned, and a practical framework that planners can adopt as protection against invasive bamboo.

Introduction

There are over 1600 species of bamboo. They occur in temperate as well as tropical and semi-tropical regions and are both woody and herbaceous. There are large bamboos as well as dwarf species; and monopodial or ‘running’ bamboos and ‘sympodial’ or clumping types.

The bamboos rhizome is the underground part of the bamboo stem. It gives out roots as well as stems or culms from the top. There are three types of rhizomes - 'running' or monopodial bamboos, 'clumping' or sympodial bamboos (hereafter referred to as running and clumping bamboos), and amphipodial or mixed types, which exhibit features of both monopodial and sympodial types. Running bamboos have slender rhizomes, which have a bud at every node.These buds either grow into other rhizomes or into shoots and then culms. They grow in a scattered way and over long distances. Running bamboo species with their aggressive spreading habits exhibit invasive traits. Temperate woody bamboo species from China and Japan are mostly running bamboo species. Clumping bamboos are of two types: (1) standard clumpers -the rhizome bears buds at its stem base, which grow into shoots and then stems. Every new stem-base bears new buds/shoots. These rhizomes cannot extend over long distances and grow in clumps; (2) open clumpers have longer petioles and can extend over longer distances. Tropical woody bamboo species that are found mostly in the Americas, Africa, Asia and Australia, with a few exceptions, are clumping types.

Bamboo species are a key component of the growing global forestry sector. Bamboo forests provide significant economic, social and environmental benefits. Bamboo species can be a source of food, can be used as ornamentals, or provide building material and raw material for fabric and hundreds of other products. Bamboo species, being fast growing, are a source of biomass for energy production. Over 1500 uses of Bamboo species have been identified (Scurlock, Dayton, & Hames, 2000).

Selected bamboo species have been introduced beyond their native range, most often intentionally, to boost the forest sector, improve carbon sequestration, become part of the ornamental plant trade, or become utilized for landscape improvement to restore degraded lands, control erosion and stabilize soils. Some of these species are known to be invasive, the majority of them running bamboo species, which exhibit vigorous growth and have been known to invade natural and semi-natural areas and cause significant negative impacts on biodiversity and ecosystems and their services (Akutsu, Aizawa, Matsue, & Ohkubo, 2012; Chiwa, Onozawa, & Otsuki, 2010; Ide, Shinohara, Komatsu, Kuramoto, & Otsuki, 2010; Fukushima, Usui, Ogawa, & and Tokuchi, 2015; Touyama, Yamamoto, & Nakagoshi, 1998; Umemura & Takenaka, 2015).

This study commissioned by the International Network for Bamboo and Rattan (INBAR) will identify which bamboo species are known to pose a threat to the natural environment and what can be done to reduce this risk. The results of this study are presented in two sections – firstly, to identify which species of bamboo are known to be ‘invasive’ and thus pose a risk to natural environments (see Section 1), and secondly, to study the types of actions that could be undertaken to mitigate this risk (see Section 2).

A comprehensive literature review was undertaken, as well as consultation with country experts to identify cases of evidenced invasions by bamboo species. Literature related to the invasions of bamboo species in their native range and related biodiversity impacts was also studied and documented. Practitioners and experts were consulted and reports and any literature on the management of bamboo species was studied to summarize best practices and lessons learned.

Alien and invasive alien species

An ***Alien*** species is one which has been introduced outside its natural distribution range as a result of intentional or accidental dispersion by human activity. An ***Invasive species*** is an alien species ***which has become established in a natural or semi-natural ecosystem or habitat, is an agent of change, and threatens native biological diversity*** (Convention on Biological Diversity (CBD), 2016).

Invasive species are recognised as one of five most important direct drivers of biodiversity loss and change in ecosystem services globally (Millennium Ecosystem Assessment, 2005), the others being habitat change, climate change, over-exploitation of species, and pollution. Mechanisms of impact of invasive species are many, and include competition, predation, hybridisation, and disease transmission, parasitism, herbivory and trampling and rooting. The outcomes of these impacts lead to biodiversity loss, habitat degradation, and loss of ecosystem services.

Introduction of alien species to their introduced range can be intentional/deliberate or unintentional/accidental. Some examples of intentional introductions include species introduced for aquaculture/mariculture, forestry, landscape improvement and erosion control, fisheries including for recreational purposes, and hunting. Examples of unintentional or accidental introductions include: escapes from gardens, aquaculture containment facilities, forestry, horticulture; pets and aquarium species released in the wild; transport contaminants and stowaways including in ballast water or as hull fouling organisms, and seeds carried in soil, equipment, vehicles etc.

Section 1

Impacts of bamboo species on the natural and semi-natural environment

Bamboo species have been widely introduced outside their native range most often intentionally, for economically beneficial purposes such as forestry, timber production, erosion control, landscape improvement, and agriculture purposes. Common examples include *Bambusa* spp., *Phyllostachys* spp., *Dendrocalamus* spp., *Fargesia* spp., *Gigantochloa* spp.(Invasive Species Specialist Group (ISSG), 2016). The local spread of bamboo species into natural and semi-natural areas is a result of 'escape' from forestry, horticulture and natural dispersal from planted areas. This spread, which is aggressive in many cases has resulted in severe negative impacts on species diversity and composition, on hydrology, soil nutrients, and surface run-off etc. (Akutsu, Aizawa, Matsue, & Ohkubo, 2012; Fukushima, Usui, Ogawa, & and Tokuchi, 2015; Ide, Shinohara, Komatsu, Kuramoto, & Otsuki, 2010; Ikegami, Satake, Nagayama, & Inubushi, 2014; Isagi & Torii, 1998; Blundell, Scatena, Wentsel, & Sommers, 2003; O'Connor, Covich, Scatena, & Loope, 2010; Chang & Chiu, 2015; Lin, et al., 2014; Sandhu, Shi, & Yang, 2013).

A majority of bamboo species are not known to display invasive traits. This section firstly identifies and describes those key species of introduced/alien bamboo that have evidenced data and information on their spread into natural and semi-natural areas, and impacts on biodiversity and ecosystem processes. Secondly, bamboo species displaying 'invasive' traits in their native range and their impacts have also been described.

Alien and Invasive bamboo species

A comprehensive literature review was undertaken to collate data and information related to the introduction of bamboo species outside their native range, their local spread into natural and semi-natural environments, and impacts on biodiversity, ecosystems and their services.

A database was created of all known bamboo species including annotations if they were woody, monopodial or sympodial (where information was easily available), location of their impact and a description of the impact mechanism/outcome and the source information. Also included were records of bamboo species invasions in their native range. The gathered information has been summarised below (See Annex 1 for an annotated list of invasive bamboo identified during the preparation of this review).

The majority of literature on evidenced impacts of alien invasive bamboo species is related to invasions in Japan, USA (both continental and in Hawaii and Puerto Rico), and Caribbean countries. Impact mechanisms of bamboo where competition (including suppression of understory due to dense growth and impacts of dense canopy) and flammability occurred resulted in varied outcomes such as: Modification of hydrology/water regulation, purification and quality/soil moisture; Primary production alteration; Reduction in native biodiversity; Habitat degradation; Habitat or refugia replacement/loss; Unspecified ecosystem modification; Physical disturbance; and Soil or sediment modification- bioaccumulation (Akutsu, Aizawa, Matsue, & Ohkubo, 2012; Chiwa, Onozawa, & Otsuki, 2010; Ide, Shinohara, Komatsu, Kuramoto, & Otsuki, 2010; Fukushima, Usui, Ogawa, & and Tokuchi, 2015; Touyama, Yamamoto, & Nakagoshi, 1998; Umemura & Takenaka, 2015). Suppression of understory, habitat degradation and loss of arable land is reported in Jamaica, where bamboo

used as stakes in agricultural systems has grown and invaded these areas, resulting in the abandonment of land that does not revert back to secondary forest (Mitchell, 2016).

The aggressive spread of bamboo species invasions in their native range were mainly recorded in China and countries in South America.

Alien and Invasive*Moso* bamboo in Japan and Taiwan

The genus *Phyllostachys* Siebold & Zuccarini, 1843, a native of China, includes over 50 species and more than 100 cultivars and varieties. *Phyllostachys* are running woody bamboos. A temperate region bamboo, it also grows in semi-tropical conditions. It is a major source of timber, paper pulp and edible shoots.

The success of *Moso* bamboo (*Phyllostachys edulis* (Carrière) J.Houz, synonyms *Phyllostachys pubescens* J.Houz**;** *Phyllostachys heterocycla* var. *pubescens*) as a viable forestry timber species and food source (shoots) has seen it being introduced outside its native range.

Moso bamboo was introduced to Japan from China via Ryukyu island in 1736 (Isagi & Torii, 1998), as a food source for its shoots and culms, and as a timber species (Fukushima, Usui, Ogawa, & and Tokuchi, 2015; Kobayashi, Fukushima, Hisamoto, & Inoue, 2015; Shozo, 2015). However, declines in the domestic bamboo industry and poor forest management caused many plantations to be abandoned, allowing unhindered growth and spread and expansion into secondary forest (Fukushima, Usui, Ogawa, & and Tokuchi, 2015; Chiwa, Onozawa, & Otsuki, 2010; Ikegami, Satake, Nagayama, & Inubushi, 2014). The dominance of this species in Japan's secondary forests – evergreen broad-leaved and coniferous forests, has been attributed to its height advantage (higher canopy position and greater average crown length) over the smaller forest species (Okutomi, Shinoda, & Fukuda, 1996; Isagi & Torii, 1998). *Moso* bamboos have also expanded into abandoned rural and agricultural landscapes (Suzuki, 2015). One study calculated the rate of range expansion of the naturalised *Moso* bamboo in Central Japan as 2.1 m per year (Isagi & Torii, 1998).

The impacts of *Moso* bamboo invasion in Japan has been studied on a variety of sites that are dominated by the species. Evidence shows that impacts are significant. See below the results of various studies:

- Change in species diversity and reduction in tree species diversity (Akutsu, Aizawa, Matsue, & Ohkubo, 2012)
- A comparative study of mymecofauna in three forest types – broadleaf forest, bamboo forest and mixed broadleaf/bamboo forest showed that myrmecofauna diversity decreased with vegetation change from broadleaf forest to bamboo dominated forest (Touyama, Yamamoto, & Nakagoshi, 1998).
- Surface runoff in *Moso* bamboo dominated forests was high caused by the high density of roots on the surface (Ide, Shinohara, Komatsu, Kuramoto, & Otsuki, 2010)
- Changes in soil chemistry (Umemura & Takenaka, 2015)
- Rapid expansion of bamboo forests is seen to cause sudden changes in nutrient/pollution fluxes (Chiwa, Onozawa, & Otsuki, 2010)
- Replacement of coniferous forests by bamboo forests has been observed to cause possible changes in terrestrial water and carbon cycles (Komatsu, et al., 2012)

- Changes have been observed in silica content in litterfall and the available silica concentration in the surface soil in bamboo forests when compared to evergreen broad leaved and coniferous forests (Ikegami, Satake, Nagayama, & Inubushi, 2014)
- Changes in the distribution pattern of Carbon and Nitrogen stored in plants and soil in invaded broad-leaved forests (Fukushima, Usui, Ogawa, & and Tokuchi, 2015).

Scientific studies conducted in a transition zone (which contained both bamboo and cedar trees) between Japanese cedar and *Moso* bamboo plantations in Taiwan concluded that bamboo invasions caused significant changes in soil microbial and bacterial activities and community structure (Chang & Chiu, 2015; Lin, et al., 2014).

Alien and Invasive bamboo in Continental USA, Hawaii and Puerto Rico

Temperate bamboo species from Asia are common horticultural imports into the USA (Smith & Mack 2013; Smith, Gomulkaiweicz, Mack, 2015) and several species have naturalised. There are reports of naturalised populations aggressively spreading, including the running woody Golden bamboo (*Phyllostachys aurea* Rivière & C.Rivière), Yellow grove bamboo (*Phyllostachys aureosulcata* McClure)*,* Bissets bamboo (*Phyllostachys bissetii*McClure)*,* Sweetshoot bamboo (*Phyllostachys dulcis* McClure)*,* Black bamboo (*Phyllostachys nigra* (Lodd. ex Lindl.) Munro)*,* and Nuda bamboo (*Phyllostachys nuda* McClure) (The University of Georgia - Center for Invasive Species and Ecosystem Health, 2016; United States Department of Agriculture (USDA)- Animal and Plant Health Inspection Service, 2012).

A survey conducted in 2008 reported that alien *Phyllostachys* spp. occupied 71,560 acres (28,960 ha) in the forests of the Southern states of the USA (Miller, Chambliss, & Oswalt, 2008).

Golden bamboo was first introduced to Alabama in 1882. It is now found in several states of the USA and invaded secondary forests, forest clearing and edges, prairies, pine woodlands, and *Pinus*-*Quercus* forests. Golden bamboo spread between two surveys - one in 1991 when no plantings were listed to 2003/2004 when golden bamboo spread across 31,440 feet² (2,921 m²) (Miller, Chambliss, & Oswalt, 2008).

Smith and Mack (2013) studied whether introduced Asian bamboo species could tolerate varied light levels in western North American coniferous forests (these forests have strong floristic similarities to East Asian coniferous forests). The results found that *Pleioblastus chino* (Franch. & Sav.), Makino (synonym *of Pleioblastus argenteostriatus* (Regel) Nakai), *Pleioblastus distichus* (Mitford) Nakai (synonym of *Pseudosasa disticha* (Mitford) Nakai), Japanese arrow bamboo (*Pseudosasa japonica (*Siebold & Zucc. ex Steud.) Makino), *Sasa palmata* (Burb.) E.G.Camus and *Sasa ramosa* (Makino) Makino & Shibata exhibit a strong tolerance to low light. The authors recommend restrictions in the importation, sale and use of these species in areas where there is potential for them to spread into coniferous forests.

*Phyllostachys nigra var. henonis (*Mitford) Rendle is recorded as forming dense stands beside streams and on shaded slopes in the Hawaiian Islands of Oahu, Maui, Molokai, Kauai, and Lanai (Evenhuis & Eldredge, 2011).

Mahal bamboo (*Bambusa longispiculata Gamble)*, Indian timber bamboo (*Bambusa tulda Roxb*.), Buddha's belly (*Bambusa tuldoides* Munro), Common bamboo (*Bambusa vulgaris* Schrad.), Calcutta bamboo (*Dendrocalamus strictus* (Roxb.) Nees), all woody and clumping bamboos, were introduced intentionally to Puerto Rico in the 1920s and 1930s for erosion

control. They were planted along steep roads and have subsequently spread through vegetative means forming monocultures, especially in riparian zones. It is speculated that broken rhizomes bits can be transported by water courses and deposited downstream to begin new plantings, but this pathway of spread needs to be researched further. Although this species is not spreading rapidly, there are concerns of dispersal through streams, and the establishment of monocultures could impact on native species (O'Connor, Covich, Scatena, & Loope, 2010; Blundell, Scatena, Wentsel, & Sommers, 2003). O'Connor, Covich, Scatena, & Loope, (2010) found that introduced bamboo species, with their heavy leaf fall may alter food availability and the habitats of stream macroinvertebrates, and impact on species composition due to their spread.

Alien and Invasive bamboo reports

While bamboo species are not a declared pest in the Queensland State of Australia, there are reports of running bamboo *Phyllostachys* spp., and clumping *Bambusa* spp. spread into natural environments in South East Queensland and northern New South Wales (Queensland Government, 2015).

Results of a study indicated that the spread of alien Common bamboo on Cousine Island, Seychelles, had impacts on the foraging behaviour and density of the endangered Seychelles giant millipede *Sechelleptus seychellarum* (Desjardins, 1835) (Lawrence, Samways, Kelly, & Henwood, 2013).

Common bamboo is reported as invasive in the French Overseas territories of Martinique and Guadeloupe in the Caribbean (Conservatoire Botanique de Martinique (CBMq), 2015; Guadeloupe, 2015). On Martinique it is reported to colonise rainforest gaps, ridges, ravines, and the sides of rivers. It reduces native species diversity and also contributes to erosion problems(Conservatoire Botanique de Martinique (CBMq), 2015). On Guadeloupe it is reported to invade protected areas (Guadeloupe, 2015).

Common bamboo was introduced to Jamaica in the 18th century (Rashford, 1995). Rashford (1995), on the many uses of bamboo in Jamaica, observed that bamboo was widespread and occurred from sea-level to 1000m elevation, and besides being cultivated around homes, was a naturalised weed along river courses, roadways, hillsides, and abandoned agricultural land. A draft Terrestrial and Eco-regional assessment of Jamaica observed that "*Bamboo is the only invasive species for which there is an island wide data set. It is very widespread, especially in the hills of upper St. Andrew and St. Mary where is occupies extensive areas and prevents regeneration of natural forest over large areas*"(Sutton & Dorfman, 2007). No specific species were mentioned.

Hedge bamboo (*Bambusa multiplex* (Lour.) Raeusch. ex Schult.*)*, Common bamboo and Balcooa bamboo (*Bambusa balcooa* Roxb.) have been reported as naturalised in Kruger National Park, South Africa and are potentially invasive (Foxcroft, Richardson, & Wilson, 2008).

The Invasive Species Specialist Group (2016) includes several records of bamboo species listed as 'alien invasive species.' However, there is no citation on the evidence of impact. These records are being verified through a network of country editors. Some examples include: Black bamboo listed as invasive in Tanzania (BioNet EAFRINET, 2015), and alien records of Common bamboo. Common bamboo has been recorded in over 80 countries and some of the countries where this species is listed as 'invasive' include Pacific Island nations

of Tonga, Palau, Federated States of Micronesia, Fiji, and the Cook Islands; Ecuador; Brazil; British Indian Ocean Territory (BIOT)-Chagos Islands; the Philippines; Singapore; US Virgin Islands; and Trinidad and Tobago (Invasive Species Specialist Group (ISSG), 2016).

Aggressive spread of bamboo species in their native range

Over the past 30 years, previously deforested areas, shrub lands and low-yield mixed bamboo forests and plantations in China have been converted into high-yielding bamboo plantations, predominantly comprising a few specific species, especially Moso Bamboo (Bai, et al., 2013; Yang Q. P, 2015; Xu, et al., 2015). In addition to erosion problems due to disturbance (until the bamboo plantations are established), the vegetative spread of these vigorous species into the surrounding natural forest has led to loss or reduction in populations of native species, reduction in species diversity, and other impacts (Rui-Perez, M., Yang, & Belcher, 2001; Yang Q. P, 2015).

For planted *Moso* bamboo there are a number of recorded examples of its expansion into 'neighbouring' natural forests, such as the Tianmushan National Nature Reserve (Xu, et al., 2015), Tianmu Mountain National Nature Reserve (Bai, et al., 2013; Yang, Du, Chen, & Liu, 2008), and Jinggang Mountain State-level Natural Reserve(Zhu & Shangguan, 2009)), where it has been found to cause severe impacts on biodiversity.

Its dominance causes it to displace and inhibit the growth of species within that community, leading to reduction in species richness and diversity (Bai, et al., 2013; Yang, Li, Dai, Liu, & Yao, 2010; Zhang, Xiao, Nie, Chen, & Guo, Study on the Species Diversity at Moso Bamboo Stands of Different Type, 2007), and significant changes in soil microbial communities (Xu, et al., 2015). Other impacts include modification of soil structure and nutrient composition, alterations in light intensity and shading, causing lower recruitment of seedlings (Liu, Zhou, & Bai, 2011), physical disturbance, changes in litter fall and allelopathy (Bai, et al., 2013; Yang Q. P, 2015), and reduction in bird diversity (Yang, Du, Chen, & Liu, 2008).

The native *Phyllostachys bambusoides* Siebold & Zucc has been widely used for flood prevention in Japan. A large species, it also has economic value being used to make furniture, handicrafts etc. Planted along riverbanks and riparian zones, it is found to be expanding into riparian communities, causing a decline in species diversity (Suzaki & and Nakatsubo, 2001).

Studies show that fragmented forests caused by anthropogenic disturbances provide opportunities for vigorous dwarf bamboo species *Sasa chartacea*to dominate understories and subsequent decline in understory communities (Tomimatsu, et al., 2011).

In the Atlantic forests of Argentina and Brazil native bamboo species of the *Chusquea and Guadua* genera *(Chusquea ramosissima* Lindm, *Chusquea tenella* Nees, *Guadua tagoara* (Nees) Kunth) are non-dominant species in undisturbed understory. However, disturbances and formation of gaps in the canopy caused by logging causes these species to become aggressive colonisers. Impacts include changes in species composition, especially woody species diversity, alteration in soil chemistry, and nutrient cycling (Tabarelli & Mantovani, 2000; Montii, Honaine, Osterrieth, & Ribeiro, 2009; Montti, Villagra, Campanello, Gatti, & Goldstein, 2014; Montti, et al., 2011; Saha, Holbrook, Montti, Goldstein, & and Cardinot, 2009; Gallardo, Month, & Bravo, 2008; Lima, Rother, Muler, Lepsch, & Rodrigues, 2012; Rother, Rodrigues, & Pizo, 2016). *Guadua sarcocarpa* Londoño & P.M.Peterson dominated

forests occur in south-eastern Peru. Gaps in canopy and disturbance are most likely the cause for this aggressive spread (Griscom & Ashton, 2003).

Overview and summary of the invasiveness of bamboo species

There are over 1600 species of bamboo. They occur in temperate as well as tropical and semi-tropical regions and are both woody and herbaceous. There are large bamboos as well as dwarf species; and monopodial or 'running' bamboos, and 'sympodial' or clumping types. Bamboo species have been widely introduced outside their native range mostly intentionally, for economically beneficial, ornamental and other purposes, such as dune stabilisation, erosion control, and landscape improvement.

Bamboo species have demonstrated invasive traits in both their introduced range, as well as in their native range when conditions have facilitated invasion. Significant negative biodiversity and ecosystem impacts have been reported when alien bamboo species have spread locally into natural and semi-natural environments in both their introduced as well as native range.

Impact mechanisms of bamboo are mainly competition and flammability, leading to varied outcomes such as modification of hydrology/water regulation, purification and quality/soil moisture; primary production alteration; reduction in native biodiversity; habitat degradation; habitat or refugia replacement/loss; unspecified ecosystem modification; physical disturbance; and soil or sediment modification- bioaccumulation.

This assessment indicates that not all introduced bamboo species exhibit invasive traits in their introduced range. The majority of cases where there is evidenced impact or aggressive spread are attributed to monopodial or running bamboo species, primarily belonging to the genus *Phyllostachys* (*P. edulis* (*P. pubescens), P. bambusoides, P. nigra, P. nuda, P. aurea, P. aureosulcata, P. dulcis*). Demonstrated negative impacts have been reported for sympodial or clumping bamboo species in their introduced range, for e.g. in some species belonging to genus *Bambusa, Dendrocalamaus and Guadua.*

This assessment also indicates that bamboo species have demonstrated invasive traits in their native range- in China, Japan and areas of South America. Spread of these bamboos has been facilitated by conditions such as poor forest management in the case of planted forests,which has allowed vegetative spread and disturbances, both anthropogenic and natural.

Section 2

Reducing the risk of bamboo invasions and managing them

Invasiveness has been recorded for some bamboo species. Furthermore, poor forest management and disturbance, both anthropogenic and natural, has often played a key role in facilitating the spread of bamboo species. Management options, including preventative measures, such as assessing risks of species before introduction, and effective management of planted forests, will go a long way in reducing the invasiveness threat some bamboo species pose. The focus of this section is on reducing the risk of bamboo invasions and managing infestations.

Management of Alien and Invasive bamboo species

Invasive alien species management is based on the following principles - prevention as the first line of defence, early detection and rapid action when prevention fails, including eradication if feasible, and, finally, when it is not feasible to eradicate established invasions to contain spread and mitigate impacts (IUCN Invasive Species Specialist Group, 2000) (Wittenberg & Cock, 2000).

Prevention

Preventative measures include outreach and awareness raising about the impact of biological invasions, assessing risks of invasion in cases of intentional introductions, and reducing chances of unintentional introduction by effective management of pathways of introduction and containing the spread of established populations of invasive and potentially invasive species.

The most effective strategy is to prevent known and potentially invasive species from being introduced in the first instance. In most instances bamboo species have been intentionally or deliberately introduced – including, for instance, as a food source, a biofuel, agricultural purposes, soil stabilisation, to prevent erosion, restoration of degraded landscapes, hedge plants, fishing poles etc. Planting of bamboo species that are known to display invasive traits must be avoided- especially in vulnerable areas such as the edges of forests and disturbed areas.

Assessing the risks of introducing alien and potentially invasive species is critical for the prevention of biological invasions. Risk assessments are tools that can give a good indication if a species is invasive and how likely it is going be invasive in area/areas of interest. Assessments are based on the best information available at that time.

The Hawaii Pacific Weed Risk Assessment (HPWRA) site provides links to updated risk assessments of over 1700 species conducted for Hawaii and the Pacific Islands. A request for an assessment can also be made. Included are completed assessments for 10 *Bambusa* spp. including Common bamboo (Score 5 - with a recommendation to 'Evaluate' before introduction), Golden bamboo and Black bamboo (Scores of 9 and 12 respectively with a recommendation of 'High risk'), *Dendrocalamus* spp., *Drepanostachyum*, *Schizostachyum* and *Gigantochloa* species (Hawaii Pacific Weed Risk Assessment (HPWRA), 2016).

A weed Risk Assessment (WRA) using the predictive Australian weed risk assessment tool (WRA) (modified for the U.S) was undertaken for 40 selected bamboo species (22 monopodial or running bamboo species and 18 sympodial or clumping bamboo species) (Lieurance, Gordon, & Flory, 2015). Results as hypothesised by the authors of this study indicate that 72% of running bamboo species are a high risk of invasion compared to 5% of clumping bamboos, the low risk of invasion being 17% and 82% respectively. Characteristics that contribute to a high invasion potential include growth habit (running versus clumping), naturalisation history, and climate suitability (Lieurance, Gordon, & Flory, 2015).

The authors observe that the precautionary approach - selection of species with a clumping growth habit for large scale production would be advisable to reduce the probability of the introduction of invasive species. They also recommend more research and study into the ecology, allelopathy, dispersal patters, shade tolerance etc. for species of interest for large scale planting (Lieurance, Gordon, & Flory, 2015).

Several countries have enacted Legislation and Regulations related to bamboo species. Some examples are listed and described below. See Annexure 2 for an annotated list of examples of Legislations/Regulation and classification of Bamboo species.

South Africa

Arundinaria spp. is on the 'List of Prohibited Terrestrial and Freshwater Plants'. The taxonomy of *Arundinaria* spp. has been confusing. Early Bamboo taxonomy assigned species with leptomorph rhizomes to this genus, all subalpine and temperate bamboos from Asia and Africa with the exception of *Phyllostachys* were placed under this genus. Currently *Arundinaria* is recognised as a narrowly defined genus endemic to the Southeastern United States. Species have been reassigned to *Pleioblastus*, *Pseudosasa* and other genera (Triplett, 2008).

Dwarf yellow striped bamboo (*Sasa ramosa* (Makino)) is listed in 'the National list of Invasive Terrestrial and Fresh-water Plant Species Category 3' (includes prohibition from importing into South Africa, growing, breeding, trans-locating, and spreading etc.
(Republic of South Africa, 2014)).

United States of America

"*No species-specific legislation exists for bamboos, but all bamboos are technically banned for importation into the U.S. unless they are imported under a research permit. There are currently 10 of these permits held in the U.S., mostly by chapters of the American Bamboo Society who import them into quarantine nurseries that are affiliated with commercial nurseries. New imports spend one year in quarantine, after which a determination is made whether or not it poses any threat to native grasses from pathogens. The ban on bamboos arose due to concerns about a smut species affecting cereals and not their invasiveness. All of this legislation is regulated by the Animal Plant Health Inspection Service (APHIS) within the US Department of Agriculture under the Plants for planting regulations (Q-37). Recently APHIS made revisions to Q-37 to add a category of testing: Not Approved Pending Pest Risk Analysis or NAPPRA which singles out plants that could host pests, pathogens or be noxious weeds*". M. Smith (USDA-ARS Invasive Plant Research Lab), personal communication, February 2016.

The State of Connecticut has regulated the planting and sale of running bamboo “any bamboo in the genus *Phyllostachys*, including *Phyllostachys aureosulcata*” through a Public Act that came into force in 2013 (The State of Connecticut, 2013).

Golden bamboo and Yellow groove bamboo are classified as ‘Prohibited invasive species’ by the New York State Department of Environmental Conservation – no one can knowingly sell, import, purchase, transport, or introduce any prohibited invasive species through a Regulation that came into force in 2015 (New York State Department of Environmental Conservation, 2015).

A statement on the invasiveness of bamboo, including its invasiveness and control, and, notes on responsible planting and care was published by the American Bamboo Society (The American Bamboo Society, 2012).

Australia

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". *Phyllostachys* spp. is declared a 'Regionally and Locally controlled weed". 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.
(Queensland Government: Weeds of Australia, 2015; Australian Weeds Committee, 2015).

Early detection and rapid action including eradication if feasible

The most cost-effective way of managing known and potential invasive species is to monitor infestations and detect and treat new infestations or satellite populations.

Citizen scientists’ volunteer programmes in which citizen scientist and volunteers survey, monitor, and detect the arrival and dispersal are gaining popularity. Reports from these sources are stored in mapping databases for records to be verified and to inform management action (Gallo & Waitt, 2011).

EDDMapS (Early Detection and Distribution Mapping System) is one such example. Developed by the Center for Invasive Species and Ecosystem Health at the University of Georgia EDDMaps supports real time tracking of invasive species occurrences, allows for data to be submitted online and through smartphones, provides electronic early detection monitoring tools, and displays distribution maps. EDDMapS includes records of several *Phyllostachys* spp. infestations (The University of Georgia - Center for Invasive Species and Ecosystem Health, 2016).

Management of alien and aggressive bamboo species near burned areas is focused on early detection and rapid response in getting rid of infestations. Bamboo species can be expected to spread rapidly via vegetative means near such sites (Gucker, 2009).

Management of established invasions

Management of established bamboo species invasions largely involve physical, mechanical and chemical options. Options from several sources have been summarised below.

Abandoned bamboo plantings, especially in situations where they have been used as hedges, wind-breaks or screens, have become source populations for invasions. Monitoring, of these infestations and removal, where possible can reduce any further spread.

Bamboo has been extensively grown in planted forests both in its introduced and native range. Information from literature reviews indicates that these established plantations have been the source of invading populations into neighbouring ecosystems (Akutsu, Aizawa, Matsue, & Ohkubo, 2012; Bai, et al., 2013; Fukushima, Usui, Ogawa, & and Tokuchi, 2015; Chang & Chiu, 2015; Okutomi, Shinoda, & Fukuda, 1996; Suzaki & and Nakatsubo, 2001; Suzuki & Nakagoshi, 2008).

Considerations for the establishment of planted bamboo forests and the management of established plantations include:

- Location of plantations – consider proximity to forests, abandoned and disturbed areas including arable land, and areas of high biodiversity value;
- Location of plantations - consider accessibility for managers and workers to manage bamboo stands and shoots - on slopes, away from roads and pathways;
- Thinning and removal of dead culms;
- Timely reduction and removal of satellite populations.

(Suzuki & Nakagoshi, 2008; Suzaki & and Nakatsubo, 2001)

Physical

Digging up clumps can be difficult with large plants or large infestations and may require heavy equipment such as a tractor or digger. Bulldoze and root rake to excavate root crowns and rhizomes, pile, and burn.

Sharp spades can be used to dig up entire clumps or bits. A rotovator can also be used to sever edges of clumps (Royal Horticultural Society, 2016). Continuing removal will probably be necessary due to re-sprouting. Continued cutting or mowing will eventually kill most plants by exhausting food reserves.

In areas where regular monitoring is not feasible - emerging clumps can be effectively killed by covering them with black mulch which will block light and eventually kill them (Muralidharan, E. M. Pers. Comm, 2016).

Physical barrier

At the garden scale the spread of vigorous bamboo species can be prevented by erecting physical barriers to prevent the spread of rhizomes:

- Dig a trench at least 60cm (2ft) deep, but ideally 120cm (4ft) deep
- Line the sides of the trench with either solid material (such as paving slabs, corrugated iron sheets or pre-cast concrete drain sections) or with fabric (such as root barrier fabric or industrial linoleum (2mm (1/8in) thick). Butyl pond liner is not suitable, as the bamboos' underground stems can penetrate this
- Fabric ends should be overlapped by at least 30cm (1ft) and bonded with appropriate mastic

- The barrier should protrude at least 7.5cm (3in) above soil level, to prevent the bamboo stems arching over the top. The protruding edge can be disguised with decorative mulch or stones
- The planting hole should be dug so that the rootball sits slightly lower than the original depth, with 2-3cm (1in) of soil covering the original surface.

(Royal Horticultural Society, 2016)

In addition to constructing barriers, creating trenches – 12 inches wide and 12-18 inches deep - has been found to be an effective way to control the spread of bamboo species. Bamboo roots which normally lie in the top 12 inches will grow outwards to spread and can be removed with a pair of secateurs (Lewis Bamboo, 2015).

Chemical

The effectiveness of the use of herbicides to eradicate weedy bamboo was investigated in Puerto Rico (Cruzado, Muzik, & Kennard, 1961). The study found that out of the 25 different compounds tested on a total of 12 bamboo species, the most effective treatments were the application of Monuron, TCA and Dalapon to the bases of intact or cut bamboo culms and the use of Amitrole as a spray for regrowth. Combinations of these treatments were found to be most effective against Common bamboo. The authors note that highly resistant species required a second treatment. They also note that decaying of dead bamboo is slow.

In consideration of the invasiveness of Golden bamboo in the south-eastern USA, Czarnota and Derr (2007) conducted field trials to determine whether a single application of selected herbicides would control bamboo. An excerpt from their study conclusions and authors recommendations states: "*A single application of either fluazifop, glufosinate, glyphosate, or imazapyr did not provide complete control of bamboo in either container or field trials. Imazapyr provided the highest level of control in the field trials, but follow-up applications would be necessary for complete eradication. Also, imazapyr has the potential to cause damage to desirable plants growing in the vicinity of the treated bamboo. Depending on the soil type and pH, imazapyr can be readily absorbed by plants growing in close proximity, especially at the high rates used (1.7 kg ai/ha). Although not tested, multiple applications (two or three) of glyphosate may have provided complete control of bamboo. Even with the potential for severe damage via spray drift, glyphosate does not have soil activity and would be a much better choice when desirable plants are growing adjacent to bamboo. Another control option not tested would be continual shoot removal of bamboo by repeated mowing or clipping. Constant depletion of bamboo energy reserves in roots and rhizomes might possibly cause the bamboo to eventually die out. Both of these control options should be considered for future research*" (Czarnota & Derr, 2007).

Examples of chemical options have been compiled from factsheets and management plans

Cut down the canes close to ground and spray the regrowth with a mix of 200ml Amitrole plus 20ml penetrant per 10lts of water before the shoots reach 600mm. Follow-up by spraying the shoots before they re-grow to 600mm high until regrowth ceases (usually 4-6 treatments); or, cut stray emergent shoots at ground level and inject 10ml undiluted Amitrole into each stem. Amongst desirable plants spray the cut shoots with 300ml haloxyfop based herbicide (e.g. Gallant NF) and a wetting agent per 10lts water, instead of using Amitrole.

(Western Bay of Plenty District Council, 2011; Waikato Regional Council, 2012)

Inject hexazinone based herbicide (e.g. Velpar 20G) 10cm into soil at 300mm spacing on the uphill side of infestations and at 1m spacing inside infestations during dry periods. Do not apply in wet conditions or on the downhill side of Bamboo infestation as hexazinone is residual in soil and will leach to desirable downhill plants

(Western Bay of Plenty District Council, 2011).

- Cut large stems and apply foliar sprays to re-sprout tips when plants are 3 to 4 feet tall, or use restricted spray nozzles and increased spray pressures to treat leaves as high as possible
- When damage of non-target plants is a concern, repeatedly apply a glyphosate herbicide as a 10-percent solution (1 quart per 3-gallon mix) in water with a surfactant
- When there are no concerns of non-target plant damage, thoroughly wet all leaves and sprouts with Arsenal AC* as a 1-percent solution (4 ounces per 3-gallon mix) in water with a surfactant
- For greatest effectiveness, use a combination of the two herbicides. Treat in September or October with multiple applications to regrowth when adequate foliage is present
- Cut just above ground level between stem sections and immediately apply into the stem cup a double-strength batch of the same herbicide or herbicide mixture in September or October
- For treatment of extensive infestations in forest situations, apply Velpar L* to the soil surface as spots in a grid pattern at spacing specified on the herbicide label at 2 gallons of herbicide per acre.

(Miller, Manning, & Enloe, 2011)

In Australia various formulations containing glyphosate as their only active ingredient are registered for the control of bamboo in the state of Queensland, Australia. Some listed herbicides require permits for use.

Glyphosate (360 g/L) Spot spray (remove tops of bamboo shoots and spot spray actively growing foliage and/or regrowth 1–2 m tall)
Rate- 1 L per 100 L water (handgun application) 150 ml per 15 L water (knapsack sprays).

Glyphosate (360 g/L) Cut stump (cut stems back to 20 cm high and immediately pour herbicide down the hollow stem and wet the cut)
Rate-1 L per 6 L water

(The State of Queensland, Department of Agriculture, Fisheries and Forestry, 2013).

Glyphosate has been injected into culms, in Japan, to prevent spread and inhibit bamboo expansion (Ito, 2005). Culm cutting combined with soil dispersion of chloric acid-based granules (Chlorate S) has been tried in Japan (Egami 2015).

Concerns have been raised over the use of glyphosate-based herbicides and risks associated with exposures (Myers, et al., 2016). The World Health Organisation's (WHO) International Agency for Research on Cancer (IARC) concluded in a 2015 report that glyphosate is 'probably carcinogenic to humans'. A new report from the Food and Agriculture Organisation (FAO) of the United Nations (UN) and the WHO has concluded that glyphosate

is ‘unlikely to pose a carcinogenic risk to humans from exposure through diet’ (FAO/WHO, 2016).

Management of pathways of local spread

Vegetative spread of bamboo species is through the dispersal of fragments of their rhizomes and culms. It is critical to prevent the dispersal of these vegetative bits. Rhizomes and culms can be dumped as garden waste, providing opportunities to spread (O’Connor, Covich, Scatena, & Loope, 2010).

Knowledge resources on the ecology, distribution, pathways of introduction and spread, impacts and management of invasive species presented in the form of species profiles are available to stakeholders at the global, regional, national, and thematic level. Some examples include: the Invasive Species Specialist Groups- Global Invasive Species Database (GISD), the Global Register of Introduced and Invasive Species (GRIIS)-under production, and the CAB International- Invasive Species Compendium (CAB ISC). Regional resources include DASIE (Delivering Alien Invasive Species Inventories for Europe), and Pacific Island Ecosystems at Risk (PIER). The GISD, CABI ISC, and PIER all feature species profiles of the Common bamboo, Golden Bamboo and other bamboo species (IUCN SSC Invasive Species Specialist Group, 2016; CAB International, 2016; Delivering Alien Invasive Species Inventories for Europe (DAISIE), 2016; US Forest Service, 2016).

Overview and summary: managing and reducing the risk of bamboo invasions

Invasive alien species management is based on the following principles - prevention as the first line of defence, early detection and rapid action when prevention fails, including eradication if feasible, and, finally, when it is not feasible to eradicate established invasions, to contain spread and mitigate impacts.

Preventative measures include

- Outreach and awareness raising - for example on the types of bamboo that display invasive traits, suitability of species for the stated purpose, and advocating responsible use
- Assessing the risks of introducing bamboo species by undertaking location and species specific risk assessments
- Managing pathways/vectors of the introduction and spread of species
- Enacting legislation and regulations have been used by countries to restrict the planting and use of certain species of bamboo.

Early Detection and rapid response is the most cost-effective way of containing spread. Monitoring of plantings, especially in planted forests and natural areas are vital so that any spread can be detected early and satellite populations can be removed.

A range of **management options are available for managing established plantings/ plantations**, including:

- Robust plantation management protocols to prevent the spread of populations from established planted forests

- Applying physical and mechanical options such as constructing physical barriers, using trenches to prevent vegetative spread and removing plantings using heavy machinery
- Applying chemical options are indicated to be effective for both small plantings and larger areas.

Conclusion

Bamboo species have been introduced outside their natural range for a variety of reasons – including for forestry purposes, as ornamental plants, and for the restoration of degraded land. Bamboo species are an important component of the forestry industry, providing significant economic, social and environmental benefits. Some bamboo species display invasive traits and cause negative impacts on native biodiversity and ecosystems. Running types of bamboo are found to be more aggressive than clumping types. Assessing the risks of, and preventing the introduction of, invasive and potentially invasive bamboo species is the first line of defence. Early detection of invasions, eradication, containment and management of established infestations follow when prevention fails. Manual, physical and chemical options are available for control.

The absence of robust plantation management protocols in planted forests, and the abandonment of plantings/plantations are indicated as key causes for the spread of bamboo from planted forests into neighbouring natural and semi-natural areas. Habitat disturbance (both anthropogenic and natural) is another cause of rapid bamboo spread, providing opportunities for vigorous species. It is recommended to develop *'Guidelines for the wise and responsible use of Bamboo species'* to provide guidance to policy makers and managers of conservation lands and planned planted forests. Bamboo can play an important role in sustainable development, and by avoiding the introduction of running species through a robust assessment of the risks of invasion and the introduction of good forestry management practices, countries can enjoy the full benefits, while substantially reducing the risks of invasiveness.

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Annexure 1: List of Bamboo species known to be invasive

Accepted name	*Bamboo type*	Location	Invasive 'yes'	Description of threat	IMPACT_evidence (Y/N)	Impact_mechanism/ outcome	Reference
Bambusa longispiculata Gamble	*woody sympodial*	Caribbean National Forest/Luquillo Mountains, Puerto Rico	alien/invasive	Expanding bamboo monocultures in several riparian areas	yes	Change in riparian zone stream dynamics; alteration in aquatic communities that are dependent on leaf input	6
Bambusa tulda Roxb.	*woody sympodial*	Caribbean National Forest/Luquillo Mountains, Puerto Rico	alien/invasive	Expanding bamboo monocultures in several riparian areas	yes	Change in riparian zone stream dynamics; alteration in aquatic communities that are dependent on leaf input	6
Bambusa tuldoides Munro	*woody sympodial*	Caribbean National Forest/Luquillo Mountains, Puerto Rico	alien/invasive	Expanding bamboo monocultures in several riparian areas	yes	Change in riparian zone stream dynamics; alteration in aquatic communities that are dependent on leaf input	6
Bambusa vulgaris Schrad.	*woody sympodial*	US Virgin Islands	alien/invasive	Listed as 'invasive' but no evidence			76
Bambusa vulgaris Schrad.	*woody sympodial*	Caribbean National Forest/Luquillo Mountains, Puerto Rico	alien/invasive	Expanding bamboo monocultures in several riparian areas	yes	Change in riparian zone stream dynamics; alteration in aquatic communities that are dependent on leaf input	53, 6

Accepted name	*Bamboo type*	Location	Invasive 'yes'	Description of threat	IMPACT_evidence (Y/N)	Impact_mechanism/ outcome	Reference
Bambusa vulgaris Schrad.	*woody sympodial*	Martinique	alien/invasive		yes		74
Bambusa vulgaris Schrad.	*woody sympodial*	Guadeloupe	alien/invasive	Invasive in protected areas			75
Bambusa vulgaris Schrad.	*woody sympodial*	Jamaica	alien/invasive	Bamboo is very widespread, especially in the hills of upper St. Andrew and St. Mary where is occupies extensive areas and prevents regeneration of natural forest over large areas.		Competition	77
Chusquea ramosissima Lindm..	*woody*	Atlantic forest, Argentina	native/invasive	Dominant in disturbed areas and gaps	yes	Competition	39, 40
Chusquea tenella Nees	*woody*	Atlantic forest, Argentina	native/invasive	Dominant in disturbed areas and gaps	yes	Competition	39, 40
Dendrocalamus strictus (Roxb.) Nees	*woody sympodial*	Caribbean National Forest/Luquillo Mountains, Puerto Rico	alien/invasive	Expanding bamboo monocultures in several riparian areas	yes	Change in riparian zone stream dynamics; alteration in aquatic communities that are dependent on leaf input	53, 6
Guadua sarcocarpa Londoño & P.M. Peterson	*woody sympodial*	forests of southeastern Peru	native/invasive	Dominating in gaps and disturbed areas	yes	Competition	47

Accepted name	*Bamboo type*	Location	Invasive 'yes'	Description of threat	IMPACT_evidence (Y/N)	Impact_mechanism/ outcome	Reference
Guadua tagoara (Nees) Kunth	*woody sympodial*	Atlantic forest, Brazil	native/invasive	Dominating in gaps and disturbed areas	yes	Competition	38
Guadua weberbaueri Pilg.	*woody sympodial*	forests of southeastern Peru	native/invasive		yes		47
Phyllostachys aurea Rivière & C.Rivière	*woody monopodial*	USA	alien/invasive	Escaping populations are common. Non-native bamboos (*Phyllostachys* spp.) occupied 71,560 acres (28,960 ha) in 2008. Golden bamboo has negatively impacted native plant communities. In Texas extensive stands are spreading on sandy. In Hawaii, golden bamboo forms monocultures	yes	Competition, Habitat degradation	42, 73
Phyllostachys aurea Rivière & C.Rivière	*woody monopodial*	Sao Paulo, Brazil	alien/invasive	*Phyllostachys aurea* and Bamboo – Moso (*Phyllostachys edulis*) tend to behave as invasive, entering the woods and competing with native species. Bamboos spread within the forest fragments, causing the loss of local biodiversity.	yes	Competition, Habitat degradation	63

Accepted name	*Bamboo type*	Location	Invasive 'yes'	Description of threat	IMPACT_evidence (Y/N)	Impact_mechanism/ outcome	Reference
Phyllostachys aureosulcata McClure	*woody monopodial*	Connecticut, USA	alien/invasive	Dense monoculture.	yes	Competition, Habitat degradation	62
Phyllostachys bambusoides Siebold & Zucc.	*woody monopodial*	Japan	native/invasive	Aggressive spread	yes	Competition, Habitat degradation	27
Phyllostachysbissetii McClure	*woody monopodial*	Connecticut, USA	alien/invasive	Bamboo shooting up through asphalt. In some locations dense monoculture.	yes	Physical destruction	62
Phyllostachys dulcis McClure	*woody monopodial*	Fairfield County, Connecticut, USA	alien/invasive	Infestation has spread to the surrounding wetland area, under pines and further to the adjoining property.	yes	Habitat degradation	62
Phyllostachys edulis (Carrière) J.Houz, synonyms Phyllostachys pubescens J .Houz.; Phyllostachys heterocycla var. pubescens	*woody monopodial*	Tianmu Mountain Nature Reserve, Eastern China; Jinggang Mountain; Jigong Mountain, China	native/invasive	Its dominance causes it to displace and inhibit the growth of species within that community leading to reduction in species richness and diversity. Other impacts include modification of soil structure and nutrient composition, alterations in light intensity and shading-causing lower recruitment of seedlings, physical disturbance, changes in litter fall and, and reduction in bird diversity	yes	Competition, Ecosystem alteration, habitat degradation	3, 13, 49, 58, 64, 65, 68, 71

Accepted name	*Bamboo type*	Location	Invasive 'yes'	Description of threat	IMPACT_evidence (Y/N)	Impact_mechanism/ outcome	Reference
Phyllostachys edulis (Carrière) J.Houz.	*woody monopodial*	Sao Paulo, Brazil	alien/invasive	*Phyllostachys aurea* and bamboo-Moso (*Phyllostachys edulis*) tend to behave as invasive, entering the woods and competing with native species. Bamboos spread within the forest fragments, causing the loss of local biodiversity.	yes	Competition	63
Phyllostachys nigra (Lodd. ex Lindl.) Munro	*woody monopodial*	Connecticut, USA; Tanzania	alien/invasive	Dense monoculture	yes	Competition, Habitat degradation	62, 78
Phyllostachys nigra var. henonis (Mitford) Rendle	*woody monopodial*	Hawaii, USA-Oahu, Molokai and Maui, Kauai	alien/invasive	*Phyllostachys nigra* var. *henonis* (Mitford) Rendle is recorded as forming dense stands besides streams and on shaded slopes in Oahu, Maui, Molokai, Kauai, and Lanai in the Hawaiian Islands	yes	Habitat degradation	66
Phyllostachys nuda McClure	*woody monopodial*	Connecticut, USA	alien/invasive		yes		62
Phyllostachy spubescens J .Houz. for Phyllostachys edulis (Carrière) J.Houz.	*woody monopodial*	Japan	alien/invasive	Aggressive spread	yes	Competition, habitat degradation	8, 10, 11, 12, 26, 28, 29, 30, 31, 32, 33, 34, 35, 55, 56, 59, 69, 70

Accepted name	*Bamboo type*	Location	Invasive 'yes'	Description of threat	IMPACT_evidence (Y/N)	Impact_mechanism/ outcome	Reference
Pleioblastus simonii (Carrière) Nakai for Arundinaria simonii (Carrière) Rivière & C. Rivière	*woody monopodial*	Australia-Lord Howe Island (WHS)	alien/invasive	Simon bamboo (*Arundinaria simonii*) is thought to represent a major threat to the flora and fauna of the World Heritage listed Lord Howe Island and it is being actively managed by volunteers with the aim of permanently eradicating it from the island. Its potential invasiveness, and the conservation significance of the island, has also led to it being declared as a noxious weed.	yes	Like other creeping bamboos, it forms dense clumps that shade out and replace native species. These dense stands have also made nesting and burrowing difficult for many bird species in infested areas.	43
Pseudosasa japonica (Siebold & Zucc. ex Steud.) Makino	*woody*		alien/invasive	The National Park Service reports this species to be invasive in Maryland, West Virginia and Pennsylvania.	yes		45

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Annexure 2: Examples of Legislation/Regulation/Classification related to Bamboo species

Country/Region	Legislation/Regulation/classification	Comments
Australia – Australian Capital Territory (ACT)	*Phyllostachys aurea* Rivière & C. Rivière - **Noxious Weed Listing 'C4'** (Invasive Plants and Animals Committee, 2015)	**C4:** prohibited - a pest plant whose supply is prohibited in the ACT.
Australia –New South Wales	*Arundinaria spp. Arundinaria pusilla, Arundinaria simonii, Vietnamosasa pusilla* - **Noxious Weed Listing –'C3'** (Invasive Plants and Animals Committee, 2015)	**C3:** Class 3 noxious weeds are plants that pose a serious threat to primary production or the environment of an area to which the order applies, are not widely distributed in the area and are likely to spread in the area or to another area
Australia- New South Wales	*Phyllostachys* spp. **Noxious Weed Listing 'C3/C4'** (Invasive Plants and Animals Committee, 2015)	**C3:** Class 3 noxious weeds are plants that pose a serious threat to primary production or the environment of an area to which the order applies, are not widely distributed in the area and are likely to spread in the area or to another area C**4:** Class 4 noxious weeds are plants that pose a threat to primary production, the environment or human health, are widely distributed in an area to which the order applies and are likely to spread in the area or to another area Some Class 3and 4 weeds are also prohibited from sale in NSW
Australia – New South Wales	*Phyllostachys aurea Rivière & C. Rivière* - **Noxious Weed Listing 'C3'** (Invasive Plants and Animals Committee, 2015)	**C3:** Class 3 noxious weeds are plants that pose a serious threat to primary production or the environment of an area to which the order applies, are not widely distributed in the area and are likely to spread in the area or to another area Some Class 3 and 4 weeds are also prohibited from sale in NSW

Country/Region	Legislation/Regulation/classification	Comments
Australia – Western Australia	*Arundinaria* spp. *Arundinaria pusilla, Arundinaria simonii, Vietnamosasa pusilla* **Noxious Weed Listing – 'CHECK'** (Invasive Plants and Animals Committee, 2015)	**CHECK:** Western Australia provides an interactive database, the Western Australian Organism List (WAOL (https://www.agric.wa.gov.au/organisms) which should be consulted to find out the status of organisms which are categorised under the Biosecurity and Agriculture Management Act 2007 (BAM Act)
Australia – Western Australia	*Phyllostachys* spp. **Noxious Weed Listing 'CHECK'** (Invasive Plants and Animals Committee, 2015)	**CHECK:** Western Australia provides an interactive database, the Western Australian Organism List (WAOL (https://www.agric.wa.gov.au/organisms) which should be consulted to find out the status of organisms which are categorised under the Biosecurity and Agriculture Management Act 2007 (BAM Act)
Australia – Western Australia	*Phyllostachys aurea* Rivière & C. Rivière - **Noxious Weed Listing 'CHECK'** (Invasive Plants and Animals Committee, 2015)	**CHECK:** Western Australia provides an interactive database, the Western Australian Organism List (WAOL (https://www.agric.wa.gov.au/organisms) which should be consulted to find out the status of organisms which are categorised under the Biosecurity and Agriculture Management Act 2007 (BAM Act)
South Africa	Alien and Invasive Species lists in terms of sections 66(1), 67(1), 70(1)(a), 71(3) and 71A of the National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004)	**Notice 1:** Notice in respect of Categories 1a, 1 b, 2 and 3, Listed Invasive Species, in terms of which certain Restricted Activities are prohibited in terms of section 71A (1); exempted

Country/Region	Legislation/Regulation/classification	Comments
	Sasaramosa (Makino) Makino & Shibata (= *Arundinaria vagans* Gamble) **Notice 1**: **Category 3** *Arundinaria* spp. on the **Notice 4 'List of Prohibited Terrestrial and Freshwater Plants'** (Government of South Africa, 2014)	in terms of section 71(3); require a Permit in terms of section 71(1) Category 3: **Restricted Activities as defined in the Act** a. Importing into the Republic, including introducing from the sea, any specimen of a listed invasive species (Prohibited) b. Having in possession or exercising physical control over any specimen of a listed invasive species (Exempted) c. Growing, breeding or in any other way propagating any specimen of a listed invasive species, or causing it to multiply (Prohibited) d. Conveying, moving or otherwise translocating any specimen of a listed invasive species (Prohibited) e. Selling or otherwise trading in, buying, receiving, giving, donating or accepting as a gift, or in any way acquiring or disposing of any specimen of a listed invasive species (Prohibited) **Restricted Activities as defined in Regulation 6** a. Spreading or allowing the spread of any specimen of a listed invasive species (Prohibited) b. Releasing any specimen of a listed invasive species (Prohibited) c. The introduction of a specimen of an alien or a listed invasive species to offshore islands (Prohibited)

Country/Region	Legislation/Regulation/classification	Comments
		Notice 4: Prohibited Alien Species in terms of section 67(1) **List of Prohibited Terrestrial and Freshwater** (Government of South Africa, 2014)
United States of America	Table 3-50 Bamboo (Bambusoidaceae) Other than cane, leaf, or Shoot, Prohibit Entry Bamboo is regulated from all countries to prevent the entry of bamboo smut (*Ustilago shiraiana*) and other exotic pathogens. (United States Department of Agriculture (USDA), 2014)	All bamboos are technically banned for importation into the U.S. unless they are imported under a research permit. There are currently 10 of these permits held in the U.S., mostly by chapters of the American Bamboo Society. The ban on bamboos arose due to concerns about a smut species affecting cereals and not their invasiveness. All of this legislation is regulated by the Animal Plant Health Inspection Service (APHIS) within the US Department of Agriculture under the Plants for planting regulations (Q-37). (United States Department of Agriculture (USDA), 2014)

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The International Network for Bamboo and Rattan (INBAR) is an intergovernmental organisation established in 1997. INBAR is dedicated to improving the social, economic, and environmental benefits of bamboo and rattan. INBAR plays a unique role in finding and demonstrating innovative ways of using bamboo and rattan to protect environments and biodiversity, alleviate poverty, and facilitates fairer pro-poor trade. INBAR connects a global network of partners from the government, private, and not-for-profit sectors in over 50 countries to define and implement a global agenda for sustainable development through bamboo and rattan.

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