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ORIGINAL ARTICLE

Risk prioritization of bamboo species in the EPPO region

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Abstract

Bamboos are popular ornamental plants in the EPPO region though some of them have been observed to escape the confines of planting and establish in the natural environment. The aim of this study is to produce a risk-based list of bamboo species which are recorded in the natural environment in the EPPO region, and to determine if any of the species require a pest risk analysis. Forty-two bamboo species were identified as being present in the natural environment in the EPPO region. Of these, 11 species fulfil the three pre-selected criteria for species to be considered potentially harmful: (1) the species is naturalized in at least one EPPO country; (2) the species has a running dispersal behaviour (leptomorph); and (3) there is evidence of invasive behaviour in at least one country. These 11 species were prioritized using the EPPO prioritization process for invasive alien plants. Owing to their high spread potential and potential high impact, three species, namely *Phyllostachys aurea*, *Pseudosasa japonica* and *Sasa palmata*, proceeded to the second stage of the prioritization process (risk management stage). All three species were identified as having a high priority for a pest risk analysis. In 2024, the EPPO Panel on Invasive Alien Plants agreed with the results of the study but noted that further information on impacts would be beneficial and therefore the Panel agreed that *Ph. aurea* and *S. palmata* should be added to the EPPO Alert List along with the already included *P. japonica*. This will raise awareness of these species in the region and further information can be gathered to support the development of a risk assessment.

KEYWORDS

Alert List, EPPO prioritization process, invasive alien species, pest risk analysis, *Phyllostachys aurea*, *Pseudosasa japonica*, *Sasa palmata*

Priorisation des risques des espèces de bambou dans la region OEPP

Les bambous sont des plantes ornementales populaires dans la région OEPP, bien qu'il ait été observé que certaines espèces s'échappent de leur périmètre de plantation et s'établissent dans l'environnement naturel. L'objectif de cette étude est de produire une liste basée sur les risques des espèces de bambou signalées dans l'environnement naturel de la région OEPP et de déterminer si l'une de ces espèces nécessite une analyse du risque phytosanitaire. Quarante-deux espèces de bambou ont été identifiées comme étant présentes dans l'environnement naturel de la région OEPP. Parmi celles-ci, onze espèces remplissent les trois critères présélectionnés pour être considérées comme potentiellement nuisibles : (1) l'espèce est naturalisée dans au moins un pays de l'OEPP, (2) l'espèce se propage de façon traçante (leptomorphe), et (3) il existe des preuves de comportement envahissant dans au moins un pays. Ces onze espèces ont été priorisées à l'aide du processus de priorisation de l'OEPP pour les plantes exotiques envahissantes. Trois espèces, *Phyllostachys aurea*, *Pseudosasa japonica* et *Sasa palmata*, sont passées à la deuxième

étape du processus de priorisation (étape de gestion des risques) en raison de leur potentiel élevé de propagation et d'impact. Ces trois espèces ont été identifiées comme fortement prioritaires pour une analyse du risque phytosanitaire. En 2024, le Panel de l'OEPP sur les plantes exotiques envahissantes a approuvé les résultats de l'étude, mais a noté qu'il serait utile d'obtenir des informations supplémentaires sur les impacts et, par conséquent, le Panel a convenu que *Ph. aurea* et *S. palmata* devraient être ajoutées à la Liste d'Alerte de l'OEPP, aux côtés de *P. japonica* qui en fait déjà partie. Cela permettra de sensibiliser à propos de ces espèces dans la région et de recueillir des informations supplémentaires pour soutenir le développement d'une évaluation des risques.

Определение приоритетности рисков, связанных с видами бамбука в регионе ЕОКЗР

Бамбук широко используется в качестве декоративного растения в регионе ЕОКЗР, однако некоторые его виды демонстрируют способность выходить за пределы культивируемых насаждений и укореняться в естественной среде. Целью данного исследования является составление на основе учета риска перечня видов бамбука, встречающихся в регионе ЕОКЗР, а также оценка необходимости проведения анализа фитосанитарного риска для отдельных видов. Было выявлено присутствие 42 видов бамбука в природной среде в регионе ЕОКЗР. Из них 11 видов соответствуют трём заранее установленным критериям, позволяющим классифицировать их как потенциально вредоносные: (1) натурализация вида хотя бы в одной стране региона ЕОКЗР, (2) наличие тенденции к распространению (лептоморф) и (3) наличие подтвержденных случаев инвазивного поведения хотя бы в одной стране. Этим 11 видам был присвоен приоритет с использованием процесса определения приоритетов для инвазивных чужеродных растений ЕОКЗР. Ввиду высокого потенциала распространения и потенциально серьезных последствий три вида, а именно *Phyllostachys aurea*, *Pseudosasa japonica* и *Sasa palmata*, были переведены на второй этап приоритетности (управление рисками). Все три вида были признаны имеющими высокий приоритет для анализа фитосанитарного риска. В 2024 г. группа экспертов ЕОКЗР по инвазивным чужеродным растениям подтвердила результаты исследования, отметив необходимость в сборе дополнительной информации о неблагоприятном воздействии, и согласилась с тем, что *Ph. aurea* и *S. palmata* должны быть добавлены в Сигнальный список ЕОКЗР наряду с уже в него включенным видом *P. japonica*. Этот шаг повысит осведомленность о данных видах в регионе и позволит собрать дополнительную информацию для проведения оценки риска.

1 | INTRODUCTION

Bamboos are a common feature in private and public amenity areas (including botanical and zoological gardens) and in recent years their popularity has increased, as they are utilized for their elegant form and interesting biological properties (Canavan et al., 2017; Pagad, 2016). The tall structure of some bamboo species enables them to be utilized not only as garden ornamentals but also for screens for privacy or to hide structures, or as barriers. In addition to their use in small-scale horticulture, in the EPPO region, bamboos are used in large-scale plantations as second-generation bioenergy crops (Liang et al., 2023), usually as short rotation coppice (Wi et al., 2017). Other beneficial uses of bamboo include for forestry (Buckingham et al., 2014), timber production (and for wood-based derived novel materials) and erosion control (Pagad, 2016), and for promoting the CO_2 capture process (Lombardo, 2022). Bamboos are also used as materials for a number of products in different domains such as construction and furniture, as well as in newer sectors such as adsorption materials and electrode components (Lou et al., 2023). Globally, the total area of bamboo increased by almost 50% between 1990 and 2020, largely because of increases in China and India, and this has led to approximately 35 million hectares of bamboo forests and plantations distributed today in tropical, subtropical and temperate regions of the world (Brusa, 2023; FAO, 2020; Lobovikov et al., 2007). Since the first introduction of bamboo in Europe in 1827, very likely *Phyllostatchys nigra* from Japan to the United Kingdom (Lehaie, 1906), many species and about 400 different cultigens and/or taxonomic entities have been imported (European Commission, 2024).

With their popularity and variety of different uses comes an increase in the number of reports of naturalization or invasiveness, either at a local scale within and between gardens (Taylor et al., 2021), or more alarmingly

as an invasive alien species which can spread into natural environments, potentially having negative impacts on native biodiversity and ecosystem services (Buziquia et al., 2019; Canavan et al., 2017).

Bamboos (family Poaceae, subfamily Bambusoideae) are a large and diverse group of perennial flowering plants with over 1700 described species in 136 genera divided into three tribes (and 19 subtribes): Arundinarieae (temperate woody bamboos), Bambuseae (tropical woody bamboos) and Olyreae (herbaceous bamboos) (Bamboo Phylogeny Group, 2012; Clark et al., 2015; Soreng et al., 2022). There are native bamboo species on all continents except for Antarctica and Europe (Attigala et al., 2016).

There are two types of bamboo species (Attigala et al., 2016; McClure, 1966): clump forming (clumping) bamboos (pachymorph or sympodial) and running bamboos (leptomorph or monopodial). Clumping bamboo species have short, thick rhizomes that curve upwards ending in a culm, forming dense clumps with minimal spatial spread. Rhizomes of running bamboo species can spread laterally over long distances (e.g. up to 10 m) in a single growing season and can form new rhizomes or culms at nodes (Buckingham et al., 2014 and references therein).

Examples of clumping bamboo genera include *Bambusa*, *Chusquea*, *Dendrocalamus*, *Drepanostachyum*, *Fargesia*, *Himalayacalamus*, *Schizostachyum*, *Shibataea* and *Thamnocalamus*.

Examples of running bamboo genera include *Arundinaria*, *Bashania*, *Chimonobambusa*, *Indocalamus*, *Phyllostachys* (note: may remain clumping in poor or dry soils), *Pleioblastus*, *Pseudosasa*, *Sasa*, *Sasaella*, *Sasamorpha*, *Semiarundinaria*, *Sinobambusa* and *Yushania*.

Popular bamboo species in horticulture in the EPPO region mainly include running bamboos such as *Phyllostachys* species (e.g. *P. flexuosa*), *Pleioblastus* (e.g. *P. hindsii*, *P. simonii*), *Pseudosasa* (e.g. *P. japonica*), *Sasa* (e.g. *S. palmata*) and *Semiarundinaria* (e.g. *S. fastuosa*). However, plant nurseries have increasingly promoted clump-forming bamboos including *Bambusa* and *Fargesia* species in recent years.

Although both running and clumping bamboos can be invasive, the rhizomatous clonal growth habit of running species is probably the key factor promoting bamboo invasion (Xu et al., 2020). Running bamboos have a greater potential for aggressive spread compared with the clumping forms (Lima et al., 2012; Xu et al., 2020). Lieurance et al. (2018) conducted weed risk assessments for 18 running and 29 clumping bamboo species for the USA. Overall, the study showed that running bamboo species present a significantly higher invasion risk than clumping species. Only one running bamboo species (*Chimonobambusa tumidissinoda*) was identified as low risk and one clumping species (*Bambusa bambos*) was high risk for invasion. History of invasiveness elsewhere, the ability to form dense thickets and unintentional dispersal of viable rhizome pieces were associated with significantly greater predicted risk (Lieurance et al., 2018).

There are a number of alien bamboo species that have shown negative impacts at a global level, including on native diversity of plants and higher trophic levels (Buziquia et al., 2019; Chen et al., 2022; Qiu et al., 2023; Wang et al., 2016). Impacts occur in terrestrial habitats, namely habitat degradation and modification (Lima et al., 2012), physical disturbance (Taylor et al., 2021), soil quality and sediment modification (Liu et al., 2019), and bioaccumulation of chemicals (Suzaki & Nakatsubo, 2001; Takano et al., 2017; Xu et al., 2020).

Negative impacts of bamboo species have been recorded in both their native and non-native ranges (Canavan, Kumschick, et al., 2019a). Impacts in the native range are often associated with intensive use of the species such as increased propagule pressure such as timber production or demand for bamboo products. Spread and negative impacts can also be driven by land-use change owing to increased planting. As an example (taken from Canavan, Kumschick, et al., 2019a; Canavan, Meyerson, et al., 2019b and the references within), *Phyllostachys edulis* is native to China and its spread in forests is associated with changes to the spatial distribution of plant communities, declines in bird diversity, declines in forest-floor ants and increased microbial biomass and diversity in areas where *P. edulis* dominates compared with native broadleaf forests. Moreover, *P. edulis* stands change nutrient/pollutant fluxes in forest floors including changes to carbon (C) and nitrogen (N) properties of the soil, lower soil N availability and slower cycling rates of N compared with secondary evergreen broadleaved forests.

In the non-native range, similar patterns are seen. For example, Wang et al. (2016) showed that the invasion of *P. edulis* in native secondary forests in Japan causes changes to soil properties by affecting soil microbial communities and the decomposition pattern of soil organic matter. In China, the invasion of *P. edulis* in Hinoki forests is associated with increased soil pH, higher silica content in bamboo litterfall compared with other forest types in Japan, as well as higher silica concentrations in surface soils. This results in the accumulation of huge biogenic pools of silica. Additionally, extensive naturalization of running bamboo species has been considered to potentially increase the numbers of rodent populations with accompanying increases in parasite transmission in the USA (Mack & Smith, 2011).

Taking into account the large diversity of bamboos and their widespread use at a global level, the actual number of invasive alien bamboo species is relatively low, as is the number of countries where invasions are reported. However, to-date there are few risk assessments conducted for bamboo species in the EPPO region, even though there are some clear examples of species showing invasive tendencies and behaviour (e.g. Brusa, 2023; Marchante et al., 2014). One reason for the lack of risk assessments is the difficulty in identifying and distinguishing bamboo species, particularly outside their native

range and when in trade. Additionally, there may be no clear justification for conducting a risk assessment on one species compared with another species, as bamboo genera have many species and bamboo species share similar biology and often exhibit comparable invasive tendencies without any scientific studies on impact.

In this context, the aim of this study is to produce a risk-based list of bamboo species which are recorded in the natural environment in the EPPO region, and to determine if any of the species require a detailed pest risk analysis. The focus of the study is on the risk posed by bamboos themselves, not as a potential pathway for other pests if they are introduced as plants for planting.

2 | METHOD

2.1 | Data gathering

A list of bamboo species present in the natural environment in the EPPO region (52 member countries: https://www.eppo.int/ABOUT_EPPO/eppo_members) was compiled from current literature sources, including online databases and floras (Appendix S2). This provided a general overview of the number of species and the most frequently observed species in the EPPO region.

The list was presented to the EPPO Panel of Invasive Alien Plants (in 2022), which currently includes 18 experts from different countries throughout the EPPO region. Experts were asked to provide a list of additional bamboo species that are present in their own country along with supporting evidence. The sources that were included were only those that ensured reliability and accuracy of the records, i.e. refereed scientific journals, non-refereed floristic journals, (unpublished) records from taxonomic specialists, herbarium collections and national databases as well as reference floras for each country.

2.2 | Categorization

All bamboo species were assigned a status for each country, i.e. cultivated (e.g. short rotation coppice), casual, established, invasive or unknown status, based on the respective sources. In addition, species were divided into traits (i.e. running or clumping bamboos). Then, to exclude those bamboo species which do not pose a risk (or only a very low risk) to the EPPO region, the following three criteria were used to identify bamboo species that pose a risk. All three criteria listed below had to be met for the bamboo species to proceed to the next level of the assessment and were applied stepwise (see Section 2.3):

(1) The bamboo species should be established in the natural environment in at least one EPPO country. The status of the species in each EPPO country was taken from the respective sources (see above).

(2) The species should have a running dispersal behaviour. Overall, studies showed that running bamboo species present a significantly higher invasion risk than clumping species (apart from some *Bambusa* spp., although these are not established in the EPPO region) (Lieurance et al., 2018).

(3) There is evidence of invasive behaviour in at least one country globally. The classification was based on different sources and included risk assessments, official lists of invasive plants and the scientific literature showing that the species has an impact on biodiversity, agriculture or forestry.

2.3 | Prioritization

The bamboo species that fulfilled all the above three criteria were assessed through the EPPO prioritization process. A detailed assessment of this process and the methodology is given in EPPO (2012) and summarized briefly here. A decision tree for the EPPO prioritization process for invasive alien plants is presented in Figure 1. The prioritization process consists of two parts where the first part (A) is used to determine if the species should be classified into one of three lists: (1) the EPPO List of Minor Concern (Minor Concern List); (2) the EPPO Observation List (Observation List); or (3) the EPPO List of Invasive Alien Plants (List IAP). The species is assessed by answering questions on its status in the area under assessment, and on its establishment potential. A species is included on one of the three lists by combining the highest rating of impact with spread potential (Figure 1).

Only those species included on the EPPO List of Invasive Alien Plants are assessed further with the second part of the prioritization process (Part B). In this section, three questions determine the priority for an EPPO pest risk assessment (PRA). The first two questions require a 'yes' answer to proceed or the species is not suitable for a risk assessment and national control measures should be adopted. The final question (B.3 Figure 1) assesses if the species has a suitable area of further spread in the EPPO region; if the area is determined as large, the species is a priority for PRA; if the area is medium, it has a lower priority; and if the area is small, it is not a priority for PRA.

Information was collected from scientific publications and databases to answer the questions in the prioritization process. Expert opinion was used when there was a lack of information on specific questions.

2.4 | Modelling the potential distribution

To provide information for those questions in Part B of the prioritization process, species potential distribution maps were produced for those species included on the List of Invasive Alien Plants.

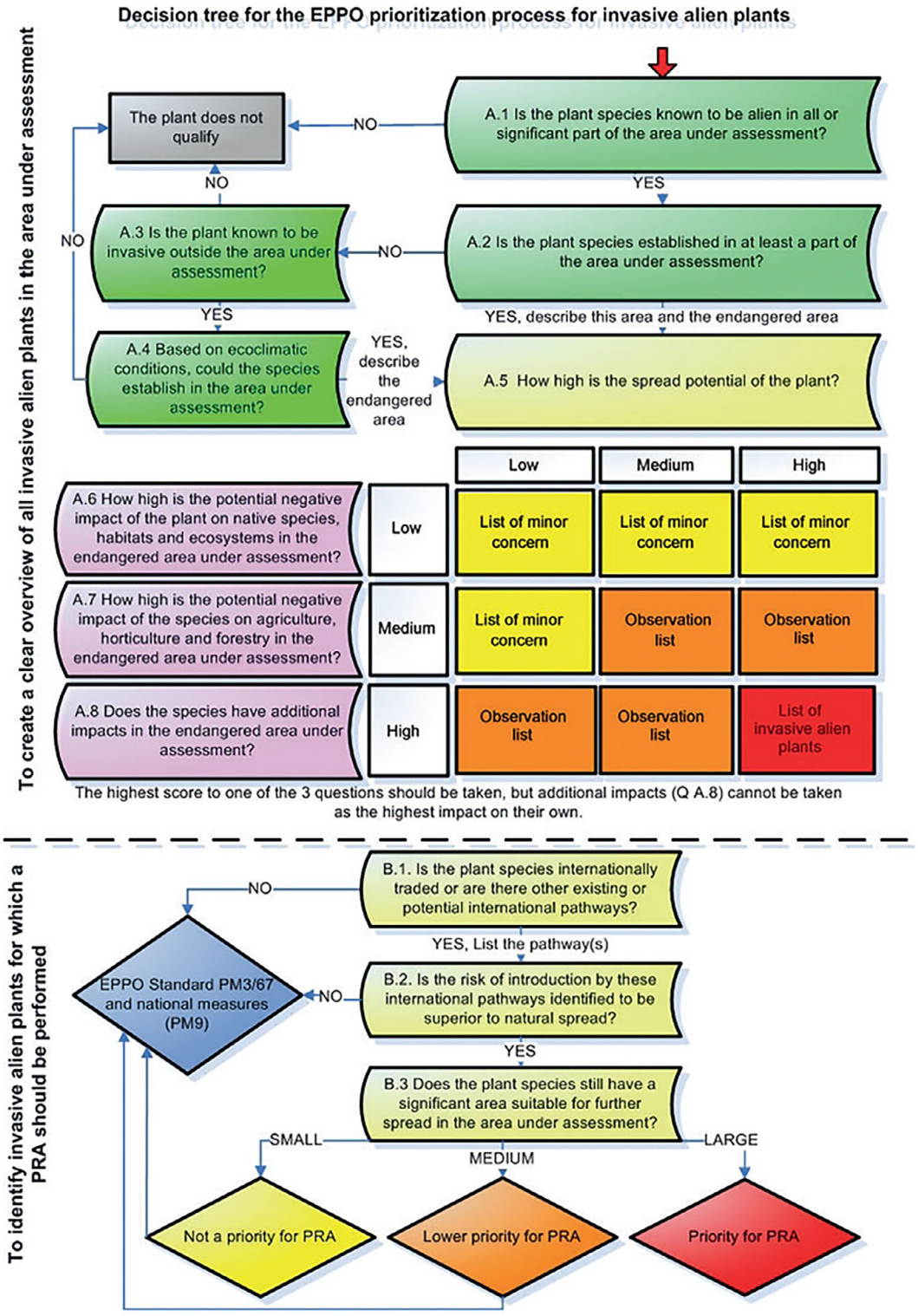

FIGURE 1 Decision tree summarizing the EPPO prioritization process for invasive alien plants (reproduced from EPPO Standard PM 5/4, EPPO, 2012).

To predict the area of the EPPO region that may currently be climatically suitable for establishment of the three species prioritized above, global-scale species distribution models (SDM) were developed. Full details of the models are given in Appendix S1. Briefly, global distribution records for the species were obtained from the Global Biodiversity Information Facility (GBIF.org, 2024) and cleaned using the CoordinateCleaner R package (Zizka et al., 2019). From these records, SDMs were produced at a 0.125° spatial resolution and using four predictor climate variables derived from CHELSA v2 (Karger et al., 2017, 2018). The chosen predictors

were mean temperature of the warmest quarter (bio10), mean daily minimum temperature of the coldest month (bio6) and mean monthly precipitations of the warmest and the coldest quarters (bio18 and bio19). The SDMs were developed using the biomod2 R package (Thuiller et al., 2023) with methods adapted for emerging invasive species that have been used in previous EPPO pest risk assessments for invasive plants (Chapman et al., 2019). The fitted SDMs were used to map suitability in the EPPO region, and suitable areas were identified using a suitability threshold selected to give 95% sensitivity (i.e. when 95% of occurrences fall inside the suitable area).

3 | RESULTS

3.1 | Pre-screening

In total, 42 bamboo species were identified from 21 countries in the EPPO region, of which 22 species were identified as being established in the natural environment in at least one country (criterion 1) (Appendix S2). The authors do not suggest that this list of bamboo species is exhaustive; however, the most popular species in horticulture/cultivation are included.

Eleven of the 22 species were running bamboos (leptomorph) (see criterion 2) and for all 11 species there was evidence of invasive behaviour (Table 1). Evidence included scientific publications detailing studies that quantitatively assessed spread and impacts of some species or qualitative information detailed in publications or databases.

3.2 | EPPO prioritization process

The first stage of the prioritization process (Brunel et al., 2010; EPPO, 2012) assigned one bamboo species to the Minor Concern List, seven bamboo species to the Observation List and three bamboo species to the List IAP (Table 1). All species are non-native to the EPPO region with the exception of *Sasa palmata*, which is native to the Kuril and Sakhalin Islands in the Russian Far East (POWO, 2024). However, owing to the species being native to only a limited part of the EPPO region, the species was included in the study. Furthermore, in Japan, although native, it is sometimes managed as a weed as it can interfere with forest regeneration (Masaki et al., 2021).

3.3 | Spread

For the scoring of spread, both natural spread and human assisted spread (e.g. planting and trade) are taken into account. For bamboos, the rate of natural spread via fruit (caryopsis hereafter referred to as seed) in the invaded range is difficult to assess, since seeds are rarely produced and the rate of germination is low under competition. Nevertheless a medium rate may be observed for plants reproducing vegetatively (EPPO, 2012). The EPPO prioritization process provides guidance where a species may score a high spread potential if it is 'spread unintentionally by human activities' such as as a contaminant of soil or habitat material, by farm or other used machinery or by dumping of plant material (such as garden waste). Through expert elicitation, the majority of bamboo species (~70%) were estimated to have a moderate spread potential in the EPPO region. Vegetative reproduction and spread are known to occur, although limited to a relatively short distance; however, human-assisted mechanisms may assist long-distance spread. Where there was evidence of significant spread, a high rating was given (e.g. spread into natural habitats in the EPPO region) (Table 1).

3.4 | Impacts

Three factors – (1) impacts on native plant species, (2) impacts on agriculture and forestry and (3) other impacts, e.g. on animal and human health, on infrastructures, on recreational activities and other trade-related impacts, such as market losses – were evaluated and the highest of the three scores was used in the assessment. The majority of recorded impacts were on native plant species and at higher trophic levels outside the EPPO region. Through expert elicitation, it was decided to score these impacts with a medium score and a high uncertainty, based on the premise that impacts have been recorded elsewhere, but it is not clear if such impacts will occur in the EPPO region. A high score for impact was given when there was evidence (reports) of negative impacts of a bamboo species in the EPPO region (Table 1).

3.5 | Assigning species to EPPO lists

Table 1 shows the overall score from Part A of the prioritization process, where a low spread potential or a low impact coupled with a low, medium or high spread potential assigns the bamboo species to the Minor Concern List. A medium impact score, coupled with a medium or high spread potential, or a high impact score coupled with low or medium spread potential, assigns the species to the Observation List. A high impact score coupled with a high spread potential categorized the species in the List IAP. The three species which were included in the List IAP and proceeded to the next stage (Part B) were *Phyllostachys aurea*, *Pseudosasa japonica* and *Sasa palmata*.

TABLE 1 Results of the prioritization exercise (Stage 1). The first stage of the prioritization process categorized three bamboo species on the List of Invasive Alien Plants (List IAP), seven bamboo species on the Observational List (Obs. List) and one species on the List of Minor Concern (Minor Concern List). Uncertainty is represented by (L) low, (M) medium or (H) high. EPPO region countries are identified by ISO codes.

Species	Alien to the EPPO region?	Established in the EPPO region?	Potential for spread	Impact on native species, habitats and ecosystems	Impact on agriculture, horticulture and forestry	Any additional impacts	Conclusion of stage 1
Chimonobambusa quadrangularis (Franceschi) Makino	Yes (native to China, Taiwan Vietnam)	Yes (FR, GB)	Medium (M)	Low (M): In Asia, impacts are reported on biodiversity in tropical regions (Indonesia: Damayanto & Muhaimin, 2017)	Low (M): No recorded impacts	Low (M): No recorded impacts, potential to impact infrastructure	Minor Concern List
Phyllostachys aurea (André) Rivière & C.Rivière	Yes (native to China, Vietnam)	Yes (ES, FR, IT, PT)	High (M): Spread observed in the EPPO region (Pittarello et al., 2021)	High (M): In USA and Australia, dense monocultures outcompete native species (Maryland Department of Agriculture, 2016; Romanowski, 1993; Weeds Australia, 2019a). Invasive behaviour reported in the EPPO region (Fried, 2012; InfoFlora, 2021; Lonati et al., 2019; Montagnani et al., 2018)	Low (M): No recorded impacts	Medium (M): Impacts reported on infrastructure in invasive range	List IAP
Phyllostachys aureosulcata McClure	Yes (native to China)	Yes (DE)	Medium (M)	Medium (H): Forms dense stands and displaces native species (Xu et al., 2020). In USA (Maryland) spreads into natural habitats from planted areas (Maryland Department of Agriculture, 2016)	Low (M): No recorded impacts	Medium (M): Rhizomes can impact infrastructure (InfoFlora, 2021, Taylor et al., 2021)	Obs. List
Phyllostachys edulis J.Houz.	Yes (native to China)	Yes (IT)	Medium (M)	High (L): In Asia, simplifies community structure, reduces plant diversity and tree regeneration and affects soil physical and chemical properties and microbial communities (Chen et al., 2022; Liu et al., 2019; Tian et al., 2020)	Low (M): No recorded impacts. Potential to impact forests for timber production	Low (M): No recorded impacts, potential to impact infrastructure	Obs. List
Phyllostachys flexuosa Rivière & C.Rivière	Yes (native to China)	Yes (DE, ES, IT)	Medium (M)	Medium (H): Considered invasive in Cuba and New Caledonia (Gargominy et al., 1996; Oviedo et al., 2012)	Low (M): No recorded impacts	Low (M): No recorded impacts, potential to impact infrastructure	Obs. List
Phyllostachys nigra (Lodd. ex Lindl.) Munro	Yes (native to China)	Yes (IT, PT)	Medium (M)	Medium (H): Forms dense stands and displaces native biodiversity (Xu et al., 2020). Reported as invasive in Tanzania (BioNET-EAFRINET, 2024)	Low (M): No recorded impacts	Low (M): No recorded impacts, potential to impact infrastructure	Obs. List

(Continues)

TABLE 1 (Continued)

Species	Alien to the EPPO region?	Established in the EPPO region?	Potential for spread	Impact on native species, habitats and ecosystems	Impact on agriculture, horticulture and forestry	Any additional impacts	Conclusion of stage 1
Phyllostachys reticulata K.Koch	Yes (native to China)	Yes (IT)	Medium (M)	Medium (H): Forms dense stands and displaces native biodiversity (Suzaki & Nakatsubo, 2001)	Low (M): No recorded impacts	Medium (M): Rhizomes can impact infrastructure (InfoFlora, 2021; Taylor et al., 2021)	Obs. List
Pleioblastus simonii (Carrière) Nakai	Yes (native to Japan)	Yes (FR)	Medium (M)	Medium (H). In Australia, reports of negative impact on biodiversity including higher trophic levels (Weeds Australia, 2019b)	Low (M): No recorded impacts	Low (M): No recorded impacts, potential to impact infrastructure	Obs. List
Pleioblastus viridistriatus (Regel) Makino	Yes (native to Japan)	Yes (IT)	Medium (M)	Medium (H): Reduces species diversity and has a major effect on soil chemicals (Qiu et al., 2023)	Low (M): No recorded impacts	Low (M): No recorded impacts, potential to impact infrastructure	Obs. List
Pseudosasa japonica (Siebold & Zucc. ex Steud.) Makino ex Nakai	Yes (native to Japan, South Korea)	Yes (BE, CH, DE, DZ, ES, FR, GE, IE, IT, NL, PT, GB)	High (M) Spread observed in the EPPO region (Booy et al., 2015; Pittarello et al., 2021)	High (M): Displaces native species (Xu et al., 2020). Invasive behaviour reported in the EPPO region (InfoFlora, 2021; Invasive Species Northern Ireland, 2024)	Low (M): No recorded impacts	Medium (M): Rhizomes can impact infrastructure (InfoFlora, 2021; Taylor et al., 2021)	List IAP
Sasa palmata (Burb.) E.G. Camus	Yes (native to Russian) Far East, Japan	Yes (BE CZ, DE, FR, IE, GB)	High (M) Spread observed in the EPPO region (Booy et al., 2015; Velekei, 2020; Rüttnauer & Reif, 2023)	High (M): Displaces native species (Fujimura et al., 2017) and prevents natural regeneration (Masaki et al., 2021). Invasive behaviour reported in the EPPO region (Invasive Species Northern Ireland, 2024)	Low (M): No recorded impacts	Low (M): No recorded impacts, potential to impact infrastructure	List IAP

FIGURE 2 Dense stand of *Phyllostachys aurea* on approx. 2000 m^2, limited by a surrounding canal near Chioggia, Italy (EPPO Global Database, Courtesy Swen Follak).

FIGURE 3 Small stand of *Pseudosasa japonica* at the edge of an open forest in Germany, near Freiburg (EPPO Global Database, Courtesy Swen Follak).

FIGURE 4 *Sasa* sp. plants spreading in public amenity planting along a cycle path, Wageningen, Netherlands (EPPO Global Database, Courtesy Jesse Beyer).

TABLE 2 Environmental requirements and habitats at risk by the different species of bamboo assigned to the EPPO List of Invasive Alien Plants according to the prioritization exercise (Stage 1).

Factor/species	*Phyllostachys aurea*	*Pseudosasa japonica*	*Sasa palmata*
Light conditions	Full sun but also can tolerate shaded conditions	Can tolerate full shade	Can tolerate partial shaded conditions
Soil type	Wide range of soil type tolerance	Well-drained moist soils and fertile soil	Well-drained moist soils
Habitats at risk	Ruderal, riparian habitats, woodland	Urban and ruderal habitats, roadsides, riparian habitats, woodland	Ruderal, damp woodland, riparian habitats

TABLE 3 Results of the EPPO prioritization exercise applied to the species selected during Stage 1 (Stage 2).

Species	Internationally traded or other international pathways?	Risk of international pathways superior to natural spread?	Significant area suitable for further spread?	Conclusion of stage 2
Phyllostachys aurea	Yes (traded as an ornamental)	Yes – international trade into and within the EPPO region is likely to be superior to natural spread	Yes (potential for spread in the Atlantic, Black Sea, Continental, Macaronesia, Mediterranean and Pannonian biogeographical regions)	Priority for an EPPO PRA
Pseudosasa japonica	Yes (traded as an ornamental)	Yes – international trade into and within the EPPO region is likely to be superior to natural spread	Yes (potential for spread in the Atlantic, Black Sea, Continental, Macaronesia, Mediterranean and Pannonian biogeographical regions)	Priority for an EPPO PRA
Sasa palmata	Yes (traded as an ornamental)	Yes – international trade into and within the EPPO region is likely to be superior to natural spread	Yes (potential for spread in the Atlantic, Black Sea, Continental and Mediterranean (limited) biogeographical regions)	Priority for an EPPO PRA

Abbreviation: PRA, pest risk assessment.

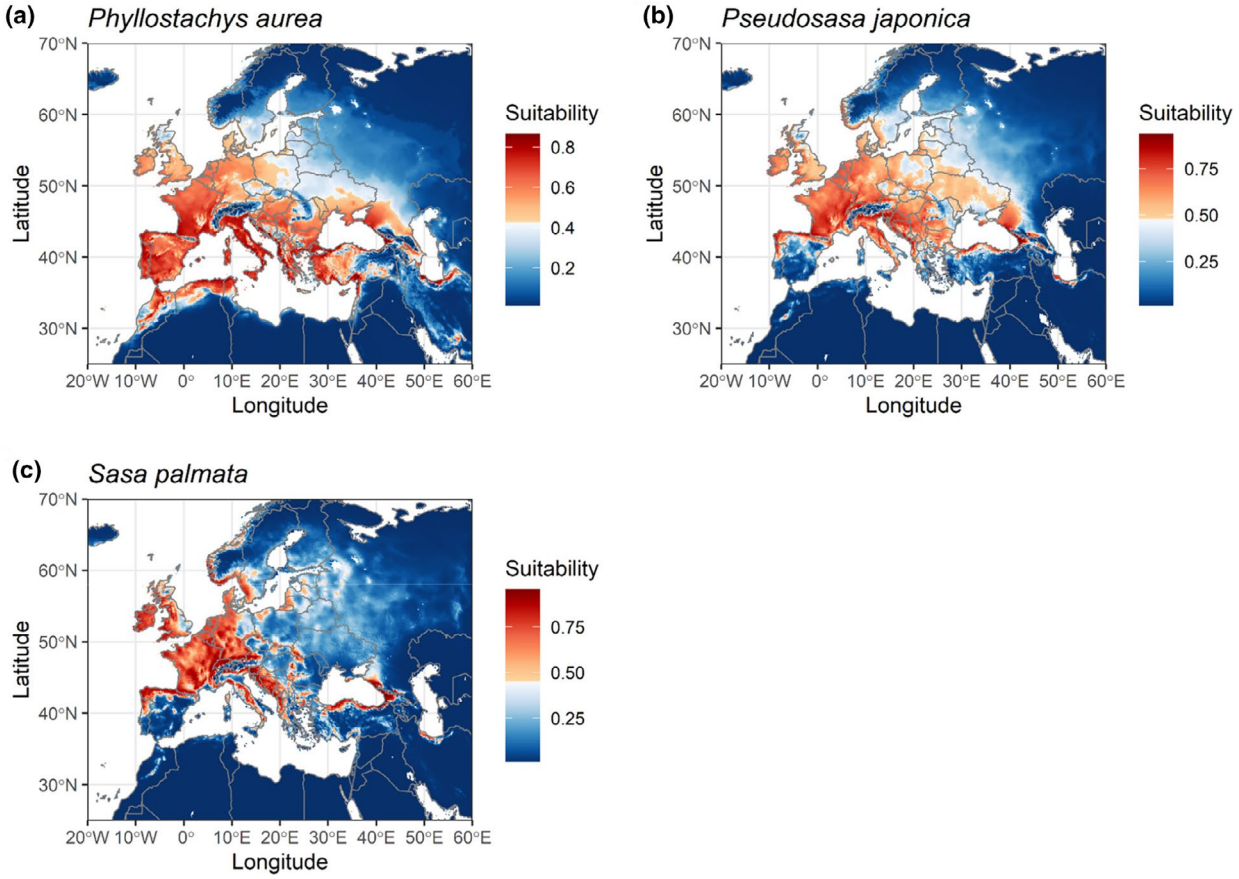

FIGURE 5 Projected climatic suitability for the three bamboo species categorized to the EPPO List of Invasive Alien Plants, produced by the species distribution models. The colour scale shows the modelled suitability scores, with the orange areas being suitable for the species.

3.6 | Part B – prioritizing species for risk assessment

All three species (*Ph. aurea* (Figure 2), *P. japonica* (Figure 3) and *S. palmata* (Figure 4)) selected for Part B were considered as a high priority for a PRA at the EPPO level. These species have the potential to occur in a variety of different habitats and can tolerate varying environmental parameters (Table 2). All species are traded internationally (Table 3). Although a lot of propagation material is sourced and propagated within the EPPO region, international movement is likely to occur between countries in the region and from countries outside of the region.

The risk of introduction by the horticulture trade is likely to be superior to natural spread. Introductions via trade pathways can act to spread the species into areas where they are currently absent.

The species distribution models for the three species suggested large climatically suitable areas with potential for much wider establishment than has currently been observed (Figure 5). Most of Western Europe is predicted to be suitable for all three species. More arid areas such as Central Iberia, North Africa and Southern Russia are largely predicted to be suitable for *Ph. aurea*, while *S. palmata* may have the greatest potential to establish in Scandinavia, especially on its Atlantic coast. The models suggest that cool summer temperatures limit suitability in north-western Europe for all species. For *Ph. aurea* and *P. japonica* cold winter temperatures limit suitability in eastern Europe, while for *S. palmata* low winter precipitation is more important. Low precipitation limits suitability around the Mediterranean basin. For further information see Appendix S1.

4 | DISCUSSION

Prioritizing invasive alien plants is an important prestep to assess risk. The EPPO prioritization process (Brunel et al., 2010; EPPO, 2012) is intended as a simple and flexible tool to provide consistent lists of invasive alien plant species for the EPPO region. The tool can be adapted for different regions and is particularly effective when prioritizing lists of species (Branquart et al., 2016; Tanner et al., 2017). The present study set out to prioritize bamboo species to (1) categorize species into EPPO lists of invasive plants and (2) identify those species where a pest risk analysis should be conducted. Of the 11 prioritized species, this study assigned one bamboo species to the Minor Concern List, seven species to the Observation List and three species to the List IAP. All species included in the List IAP were further assessed and deemed a priority for PRA. *Phyllostachys aurea*, *P. japonica* and *S. palmata* all show spread and invasive behaviour in the natural environment in at least one EPPO country and through risk analysis, the potential economic impact of the species can be evaluated along with potential impacts on biodiversity and ecosystem services.

At present, no bamboo species are listed under the Regulation (EU) no. 1143/2014 on the prevention and management of the introduction and spread of invasive alien species. EPPO has included one species, *P. japonica*, in the EPPO Alert List (EPPO, 2020), where the purpose of listing is to raise awareness of the species to member countries, but also to seek information from countries on negative effects. Nationally and regionally, bamboo species are included on 'blacklists' of species which should not be grown and/or are banned from sale. These lists can limit the use of species in protected areas or in areas that are considered endangered by the species. At a national level, restricting the use of potentially invasive species can effectively act to prevent its entry into the natural environment. In Switzerland, *Ph. aurea* and *P. japonica* are regulated by national law (FrSV SR 814.911 amended 1 September 2024) and it is prohibited to sell, exchange (etc.) or import them for handling in the environment, not including the handling of therapeutic products and human and animal food products.

Bamboos have been recorded in a variety of habitats in the EPPO region with the number of garden escapes recorded increasing (Taylor et al., 2021). They are associated with man-made habitats, such as roadsides, uncultivated fields, abandoned nurseries, ditches and gravel pits, and with natural habitats (Pittarello et al., 2021). Fried (2012) notes that *Ph. aurea* is invasive along rivers in the Mediterranean region. European rivers are vital habitats for endemic biodiversity and natural resources and are prone to invasion for an array of invasive plant species. Adriaens et al. (2019) record *P. japonica* occurring in coastal dune systems in Belgium and there are a number of reports of bamboos in natural woodland habitat in the EPPO region (Brusa, 2023; Pittarello et al., 2021; Pyšek et al., 2022; Rüttnauer & Reif, 2023).

In the popular press, and in gardening forums, there are an increasing number of articles about bamboos becoming problematic in urban environments. Often, bamboo species can be referred to as vigorous growing species that can be grown but should be 'watched' or managed to avoid the species spreading within restricted areas (Canavan, Kumschick, et al., 2019a; Canavan, Meyerson, et al., 2019b). Taylor et al. (2021) note that *Ph. aurea* and *S. palmata* are two of the six most popular bamboo species for gardeners and landscapers in Great Britain and Ireland. In such anthropogenic environments, impacts are often associated with structural damage (with rhizomes pushing up concrete slabs) or with plants spreading beyond where initially planted, causing disputes between neighbours (Taylor et al., 2021). Often these impacts are local, although it can be difficult to control such populations, especially following their escape into the natural environment. In Ireland, the risk of *S. palmata* was estimated as low

(Invasive Species of Northern Ireland, 2024). However, Lima et al. (2012) note that although impacts are local, where it is present in woodlands, it can prevent regeneration of native species. This in itself suggests that the potential risk of the species might be medium. The negative impact is multiplied by the fact that bamboo species are evergreen, and therefore changes in communities may be stronger.

Bamboos are commonly planted in private gardens, parks and public areas (Pergl et al., 2016; Vojík et al., 2020) owing to their landscaping value, ability to create natural hedges, etc. As bamboos are often grown at the edges of gardens or along borders, they can spread into the natural environment from planted populations as well as through the dumping of garden waste. The latter is probably the cause of occurrences of *P. japonica* in forests in Austria (Hohla, 2018). Whereas the dumping of garden waste into the natural environment is strictly prohibited in most EPPO countries, planting bamboos in a contained location with an adequate rhizome barrier (e.g. a polypropylene plastic rhizome barrier to prevent the spread of rhizomes) can prevent spread from gardens and other amenity areas (Infoflora, 2021). Rhizome fragments may be spread over a longer distance through the transport of contaminated soil and via rivers. Bamboo species are also likely to increase their area by natural spread, although this is limited to a few metres per year (e.g. Bai et al., 2016).

The invasive potential of bamboo species will probably be facilitated by climate change (Takano et al., 2017). Within the EPPO region, climate change may act to facilitate distribution shifts and promote spread into natural habitats. This may change the status of species reported as transient to established, and thus change the level of impact in natural areas. Some areas within the EPPO region, for example the Mediterranean, are undergoing severe climatic changes and it remains unclear how invasive plant species will behave in this new climatic landscape (Pinna et al., 2024). This may mean that bamboo species are re-prioritized periodically, taking such factors into account, especially for those species on the Observation List. Additionally, species distribution models can include climate change scenarios. It is recommended that species on this list are re-prioritized every 10 years, or when significant new information on a species is published.

The popularity of bamboos does not reside with gardeners alone as other benefits are widely cited. For example, bamboos can produce more than 30% more oxygen than woody biomass (Liang et al., 2023) and can absorb between 10 and 60 tonnes of carbon dioxide per hectare per year (Cobratex, 2024; RyPax, 2024), although these values are mostly based on estimations and studies conducted in the plants' native ranges. These benefits have promoted the planting of bamboos for second-generation biofuels, which differ from first-generation biofuels in that they are not made from sugar-starch feedstocks or edible oil feedstocks, but from various types of non-food biomass (Liang et al., 2023). In the EPPO region, the industrialization of bamboo for biofuels has yet to occur at a large scale, although in the future such plantings may be considered. For future use of bamboo as a biofuel, there should be an awareness of the invasion risk for individual species and guidelines should be established to choose the best sites for plantations and monitor the risk of spread from planted sites into susceptible habitats. Especially when a bamboo plantation is abandoned, there is a risk that it will encroach into the surrounding natural habitats. Similar behaviour has been shown for other plant species (e.g. *Heracleum sosnowskyi* EPPO, 2020). Industry can consider how guidelines for other taxa (e.g. non-native tree species, Brundu et al., 2020), can be adapted to bamboo species.

Bamboos are often highlighted as having a high potential to cause negative impacts to infrastructures or local biodiversity, but exact identification of problematic species is lacking. For example, Kunttu et al. (2023) highlight a first record of an invasive bamboo species in Finland but note that the exact identification of the species was not possible (although it is probably *Pleioblastus argenteostriatus*). If misidentification can occur in the field, it is reasonable to suggest that it can also happen in trade, where potentially more invasive species could be sold, in particular as, in many cases, bamboos are shipped as rhizomes. Ambiguity in identification can complicate PRA, as often one of the questions is if the species can be clearly identified. Molecular identification (DNA barcoding) is an important tool to aid identification, especially due to the complications with morphological identification (Canavan et al., 2021). Therefore, we recommend that when projects study established or invasive populations of bamboos in the EPPO region, herbarium samples and/or molecular samples should be submitted in Q-bank Invasive Plants Database (Q-Bank, 2024, https://q-bankplants.eu/) to act as a resource for molecular data.

Controlling the spread of planted bamboo in urban or semi-urban settings can help prevent their spread into the natural environment. Measures to mitigate the spread of bamboo species from planted populations should be implemented by gardeners, landscapers and producers. This can take into account the EPPO guidelines on the development of a code of conduct on horticulture and invasive alien plants (EPPO, 2009) or other international guidelines when planted for purposes different than horticulture, as in the case of bioenergy plantations. Taylor et al. (2021) provides a comprehensive summary of bamboo management in urban gardens, including advice on chemical application, excavations of rhizomes and disposal. Additionally, they also provide useful advice on containment, including growing bamboos in containers to prevent the spread of rhizomes. Following such

recommendations can prevent the negative impacts of ornamental bamboo species.

Only a limited number of risk assessments have been developed for bamboo species in the EPPO region (e.g. SLU Artdatabanken, 2024). One reason for this may be the uncertainty in choosing one species over another. A number of bamboos are noted as having invasive behaviour, and it could be argued that a group of closely related species could be risk analysed together, rather than as single species. However, with the current process, taking the criterion of evidence of naturalization in at least one EPPO country, evidence of invasive behaviour outside of the EPPO region and running dispersal behaviour, prioritizing species is possible.

There is a lack of quantitative data for all three bamboo species herein recommended for PRA, in particular on negative impacts within the EPPO region, and beyond. Although this will not prevent a PRA being conducted, it can raise the uncertainty of the analysis. Any PRA will need to explore if and how known impacts in other regions will translate to the EPPO region. For example, invasive behaviour seen in tropical regions may not necessarily occur in the EPPO region. It should be noted that this study only included bamboo species with negative impacts where there were scientific publications detailing such impacts. However, some bamboos (e.g. *Phyllostachys viridiglaucescens*), which are established in the natural environment and show invasive tendencies, for example formation of large stands, should also be monitored and where possible assessed for negative impacts on local biodiversity and ecosystem services.

In this study, further information on impacts would be beneficial and therefore the Panel on Invasive Alien Plants agreed that *Ph. aurea* and *S. palmata* should be added to the EPPO Alert List along with the already included *P. japonica*. This can to raise awareness of these species and gather further information on negative impacts. The seven species included on the Observation List in this study should be further monitored for any future invasive behaviour.

5 | CONCLUSION

The majority of bamboo species utilized in the EPPO region are presently non-invasive and are unlikely to cause negative ecological or economic impacts under current climatic conditions. However, running bamboos present attributes associated with invasiveness and some of them were observed to have established and to have formed extensive populations in the natural environments in the EPPO region. There remains a lot of uncertainty regarding the potential for establishment, spread and impacts for future climatic scenarios or in the case of the introduction of new genotypes. Surveying bamboo species in the natural environment and recording any negative impacts can provide evidence to warrant further assessment of these species. Cautious planting of bamboos is recommended, especially those species that may have invasive tendencies. In addition, planting alternative (potential native) species providing similar services is recommended.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of the html version of this article.

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