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Ecological risk assessment of potentially invasive alien plant species in Cibodas Biosphere Reserve, West Java, Indonesia

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Abstract. More than 80 potentially invasive plant species have spread throughout the Cibodas Biosphere Reserve, Indonesia. Recently, research has shown that the surrounding community utilizes more than 50% of these species. Although this utilization provides social and economic benefits, it threatens the Cibodas Biosphere Reserve core zone ecologically. Therefore, this study conducted a risk assessment to determine the invasiveness level of utilized plant species. The evaluation was performed using Hawaii and Pacific Weed Risk Assessment (WRA) scheme. The results show that almost all the potentially invasive plant species are high risk, with scores ranging from 10 to 26, except for *Fragaria vesca* and *Mentha arvensis*. The highest WRA score was obtained for *Lantana camara* and followed by *Austroeupatorium inulifolium*, *Cobaea scandens*, *Mikania cordata*, *Sonchus asper*, *Clidemia hirta*, *Piper aduncum*, *Sonchus arvensis*, *Cestrum aurantiacum*, *Dracaena fragrans*, *Passiflora ligularis*, *Podachaenium eminens*, *Thunbergia coccinea*, and *Wedelia trilobata*. As most of these species were herbaceous plants obtained from cultivated areas, the risk of invasion into the core zone is low. Based on the findings, the recommended management option to control these species is harvesting, accompanied by containment. Through this method, the community can continue to use the species while controlling the population, thereby limiting their spread.

1. Introduction

Alien plant species are species that have spread over new areas beyond their geographic distribution [1, 2]. After these species are naturalized, they can survive and reproduce. However, these species become invasive alien plant species (IAPS) when they cause ecological and economic loss [2-4]. Richardson [5] described the growth and reproduction of IAPS, stating that for taxa that are spread by seeds or other propagules, IAPS can spread a distance of over 100 m in less than 50 years. Meanwhile, for taxa that are spread by roots, rhizomes, stolons, or vine stems, IAPS can spread more than 6 m in three years.

To date, there are 88 potentially IAPS in the Cibodas Biosphere Reserve (CBR) area [6], occurring in both the Gunung Gede Pangrango National Park (GGPNP), which is considered the core zone as well as a buffer zone [7-15]. Of these IAPS that spread, communities in the buffer zone utilize more than 50% of them [6], including the community in the Cibodas [16], Sarongge [17], and Bodogol areas [18-20]. Our previous study concerning potential IAPS utilization at three locations (Cibodas, Bodogol, and



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Gekbrong) in the CBR buffer zone revealed that at least 72 species are beneficial to the community, ten of which have high utilization value [21].

Further, the utilization of these plant species has a positive impact as they benefit the community. However, caution regarding the potential invasion of these species must be maintained. Hence, each utilized species' invasive risk level must be assessed to identify the risk level of these species and determine their proper management.

2. Methodology

Our previous research about the utilization of potentially Invasive Alien Plant Species (IAPS) in Cibodas Biosphere Reserves showed 72 species commonly used by the community [21]. From that data, we evaluate the ecological risk of every utilized species. The ecological risk assessment uses the Hawaii and Pacific Weed Risk Assessment (WRA) scheme [22]. The evaluation was performed by filling out the WRA sheet for every utilized potential IAPS. This scheme was selected because it is free, and it predicts the risk level of invasion from many species quickly and easily without conducting ground checks. The WRA was developed to identify the risk level of species invasion via a series of questions based on the characteristics of the plant species of interest. These questions include cultivation factors, climatic suitability, morphological and physiological characteristics, seed productivity and distribution, and resistance to disturbance [22, 23]. The answers to these questions are "yes" or "no" based on a literature review of several assessed species studies. The score of each "yes" and "no" is different for every question (WRA sheet 2). After the assessment is complete, the total score is calculated to determine the category of risk as follows [22]:

- a. Total score > 6 = high risk
- b. Total score 1-6 = need a second assessment
- c. Total score < 1 = low risk

Based on this categorization, we analyzed the risk level of each species relative to their bio-ecological characteristics and their location in the CBC area. Based on this analysis, we determined whether the invasive risk of every species threatened the GGPNP forest area. Additionally, determining a suitable management option based on their individual utilization is crucial for reducing the spread of these species.

3. Results and Discussion

The risk assessment results showed that all 72 species were considered high-risk for invasion, except for two species with low risk, namely *Fragaria vesca* and *Mentha arvensis* (Table 1). Several factors determine the potential level of invasiveness, including domestication or cultivation, weeds in other places, morphology, lifeform, seed reproduction, distribution mechanism, and other characteristics. Those can make the species resistant to disturbance [23]. Specifically, the cultivation factor influences the risk value, and if it is commonly cultivated, the risk value reduces significantly, as in the case of *F. vesca* and *M. arvensis*.

In low-risk *F. vesca* and *M. arvensis*, both species have been cultivated by the community for a long time. These species commonly trade in the Cibodas area, especially *F. vesca*, which produces strawberries, giving them a high economic value. Strawberries were introduced to the mountainous areas of the Cibodas Botanical Gardens in the 18th century or around the 1840s, when many other species were also introduced [24]. The history of the spread of *M. arvensis* is mostly unknown, but they were derived from Europe [25]. This species is a source of essential oils that have economic value and is suitable for the climate of Indonesia [25].

3.1. Characteristic of high-risk plant species and their introduction histories

A total of 70 potentially high-risk IAPS had WRA scores ranging from 10 to 26. The high-risk species with a WRA score of > 20 included *Lantana camara*, *Austroeupatorium inulifolium*, *Cobaea scandens*, *Sonchus asper*, *Clidemia hirta*, *Piper aduncum*, and *Sonchus arvensis* (Table 1). The species with the highest WRA score (26) is *Lantana camara*, which is from the Verbenaceae family.

Table 1. The risk level of every species based on assessment results.

Species	Family	WRA score	Risk level	Life form
<i>Ageratina riparia</i>	Asteraceae	18	high	herbs
<i>Ageratum conyzoides</i>	Asteraceae	16	high	herbs
<i>Ageratum houstonianum</i>	Asteraceae	19	high	herbs
<i>Amaranthus spinosus</i>	Amaranthaceae	16	high	herbs
<i>Artemisia vulgaris</i>	Asteraceae	16	high	herbs
<i>Austroeupatorium inulifolium</i>	Asteraceae	22	high	shrub
<i>Bartlettina sordida</i>	Asteraceae	16	high	shrub
<i>Bellucia pentamera</i>	Melastomataceae	13	high	small tree
<i>Bidens pilosa</i>	Asteraceae	19	high	herbs
<i>Browallia americana</i>	Solanaceae	19	high	herbs
<i>Brugmansia suaveolens</i>	Solanaceae	15	high	small tree
<i>Brugmansia versicolor</i>	Solanaceae	16	high	small tree
<i>Brugmansia x candida</i>	Solanaceae	16	high	small tree
<i>Calathea lietzei</i>	Marantaceae	13	high	herbs
<i>Calliandra calothyrsus</i>	Fabaceae	12	high	shrub
<i>Centella asiatica</i>	Apiaceae	13	high	herbs
<i>Cerastium glomeratum</i>	Caryophyllaceae	12	high	herbs
<i>Cestrum aurantiacum</i>	Solanaceae	20	high	shrub
<i>Cestrum elegans</i>	Solanaceae	18	high	shrub
<i>Chimonobambusa quadrangularis</i>	Poaceae	18	high	bamboo
<i>Cinchona pubescens</i>	Rubiaceae	15	high	tree
<i>Clibadium surinamense</i>	Asteraceae	13	high	shrub
<i>Clidemia hirta</i>	Melastomataceae	21	high	shrub
<i>Cobaea scandens</i>	Polemoniaceae	22	high	climber
<i>Cosmos caudatus</i>	Asteraceae	13	high	herbs
<i>Cyphomandra betacea</i>	Solanaceae	14	high	shrub
<i>Dichrocephala bicolor</i>	Asteraceae	14	high	herbs
<i>Dracaena fragrans</i>	Asparagaceae	20	high	shrub
<i>Drymaria cordata</i>	Caryophyllaceae.	18	high	herbs
<i>Emilia sonchifolia</i>	Asteraceae	15	high	herbs
<i>Erechtites valerianifolius</i>	Asteraceae	12	high	herbs
<i>Eryngium foetidum</i>	Apiaceae	14	high	herbs
<i>Euphorbia hirta</i>	Euphorbiaceae	10	high	herbs
<i>Euphorbia prostrata</i>	Euphorbiaceae	10	high	herbs
<i>Fragaria vesca</i>	Rosaceae	-1	low	herbs
<i>Galinsoga parviflora</i>	Asteraceae	13	high	herbs
<i>Gnaphalium purpureum</i>	Asteraceae	11	high	herbs
<i>Hyptis brevipes</i>	Lamiaceae	12	high	herbs
<i>Indigofera suffruticosa</i>	Fabaceae	10	high	shrub
<i>Kalanchoe pinnata</i>	Crassulaceae	12	high	herbs
<i>Lantana camara</i>	Verbenaceae	26	high	shrub
<i>Maesopsis eminii</i>	Rhamnaceae	17	high	tree
<i>Melastoma malabathricum</i>	Melastomataceae	17	high	shrub

Species	Family	WRA score	Risk level	Life form
<i>Mentha arvensis</i>	Lamiaceae	-4	low	herbs
<i>Mikania cordata</i>	Asteraceae	22	high	climber
<i>Oxalis barrelieri</i>	Oxalidaceae	10	high	herbs
<i>Oxalis corniculata</i>	Oxalidaceae	15	high	herbs
<i>Oxalis latifolia</i>	Oxalidaceae	13	high	herbs
<i>Passiflora edulis</i>	Passifloraceae	17	high	climber
<i>Passiflora ligularis</i>	Passifloraceae	20	high	climber
<i>Passiflora suberosa</i>	Passifloraceae	14	high	climber
<i>Physalis peruviana</i>	Solanaceae	11	high	herbs
<i>Piper aduncum</i>	Piperaceae	21	high	small tree
<i>Podachaenium eminens</i>	Asteraceae	20	high	shrub
<i>Salvia hispanica</i>	Lamiaceae	10	high	herbs
<i>Sida rhombifolia</i>	Malvaceae	13	high	shrub
<i>Solanum aculeatissimum</i>	Solanaceae	17	high	shrub
<i>Solanum americanum</i>	Solanaceae	14	high	herbs
<i>Solanum torvum</i>	Solanaceae	10	high	shrub
<i>Solanum verbascifolium</i>	Solanaceae	17	high	shrub
<i>Sonchus arvensis</i>	Asteraceae	21	high	herbs
<i>Sonchus Asper</i>	Asteraceae	22	high	herbs
<i>Sonchus oleraceus</i>	Asteraceae	16	high	herbs
<i>Spilanthes acmella</i>	Asteraceae	11	high	herbs
<i>Stachytarpheta jamaicensis</i>	Verbenaceae	17	high	shrub
<i>Stellaria media</i>	Caryophyllaceae.	18	high	herbs
<i>Taraxacum officinale</i>	Asteraceae	18	high	herbs
<i>Tetrapanax papyrifer</i>	Araliaceae	14	high	shrub
<i>Thunbergia coccinea</i>	Acanthaceae	20	high	climber
<i>Tithonia rotundifolia</i>	Asteraceae	16	high	shrub
<i>Viola odorata</i>	Violaceae	12	high	herbs
<i>Wedelia trilobata</i>	Asteraceae	20	high	herbs

As reported in many studies on weeds, *L. camara* is a highly important invasive species. Specifically, this species is one of the 100 most dangerous invasive species globally [26]. In addition, [27] stated that this species includes ten dangerous weeds that have invaded various global habitats. This species is reported as the 75 most important weed species in Indonesia [28]. The first record of this species was recorded in the Java state in the Bogor Botanical Gardens catalog 1866 [14] but has since spread over almost all over the country [28]. Therefore, this species is listed as an IAPS in the Ministry of Environment and Forestry Regulation [29].

[14] mentioned that *L. camara* could adapt to a variety of different habitats (mountain forests to savanna). This is evidenced by its invasion in eight national parks in Java, including Ujung Kulon, Gede Pangrango, Merapi, Merbabu, Bromo Tengger Semeru, Meru Betiri, Alas Purwo, and Baluran [14]. This species also has several characteristics that support its invasive ability, such as thorny shrubs, shade resistance, tolerance to various soil types, and fuel sources in fire-prone areas [30]. Further, its allelopathic content of decomposed leaf litter has been shown to inhibit the growth of other plant species [31]. *L. camara* also survives under shade by increasing leaf biomass, leaf size, leaf area index, and plant height and decreasing leaf thickness and stomatal density [27].

The invasive species with high WRA values include *Austro eupatorium inulifolium*, *Sonchus asper*, and *Cobaea scandens*. In addition to *L. camara*, *A. inulifolium* and *C. scandens* are also considered

important invasive species in Indonesia [28]. [32] stated that *A. inulifolium* has phenotypic plasticity or morphological and physiological flexibility, allowing it to adapt to various environmental conditions quickly. This characteristic allows the species to invade a habitat quickly. This species was introduced to the Bogor Botanical Gardens in the 1900s and then spread to the tea and quinine plantations in West Java, used as a hedge plant [14, 28, 33].

Cobaea scandens is a fast-growing climbing plant that can cover many other plant species [34]. It produces abundant fruit and seeds, is pollinated by bats, and lives in riparian areas, facilitating seeds' dispersal via water [34]. The first record of this species was in the Cibodas Botanical Garden (CBG) in 1927, and in 1930, it was officially recorded in the CBG plant catalog [15]. This species was introduced as an ornamental plant from Mexico and has since spread onto the GGPNP forest area [15, 28].

Although *Sonchus asper* is not considered an important weed species in Indonesia, it is a cosmopolitan plant with wide tolerance to various climatic conditions. In addition, it produces abundant seeds that are spread by wind, water, and agricultural activities [35, 36]. These factors play an essential role in the invasion of this species, making it a dangerous weed [36, 37]. This species was first recorded in the Bogor Botanical Gardens catalog in 1844 [14].

Clidemia hirta (local name: *harendong bulu*) is a shrub from the Melastomataceae family. [14] mentioned that this species was first discovered in Java in the late 19th century but has since spread and become naturalized in Java, Sumatra, and Sulawesi [28]. [14] also showed that it had invaded six of the eight national parks in Java, including Ujung Kulon, Gede Pangrango, Merapi, Merbabu, Bromo Tengger Semeru, and Meru Betiri. As this species has sweet, edible berries, both animals and humans play a role in spreading its seeds. The morphology of the fruit, which has soft thorns and sticky flesh, makes it easier to spread the seeds, as they attach to clothes or animal skins or are carried away during agricultural activities. The production of seeds is also abundant and can be applied in various ways, enabling this species to quickly spread and invade a habitat [38]. Further, it has an allelopathic effect that inhibits the growth of other species [39].

Piper aduncum (local name: *sirihan*) is a shrub or small tree belonging to the Piperaceae family. Hartemink [40] mentioned that this species was introduced to Indonesia in the 1860s as an ornamental plant for the Bogor Botanical Gardens. Then, in the 1920s, this species spread to the environment around the Bogor Botanical Gardens, consisting of riverbank habitats and steep slopes. This species has since spread throughout Indonesia because of its ability to proliferate in neglected or disturbed areas and open forest areas [28]. Although this species is not very resistant to shade, it can survive shade at a low growth rate [41].

Nevertheless, it will experience rapid growth under full sun, causing this species to easily grow in open areas, both individually and in groups, forming dense shrubs. This species flowers and bears fruit all year, and its seed dispersal is performed by birds, bats, and even arboreal rodents, as well as the wind [40,41]. Susanto [42] reported that *P. aduncum* seeds have a fast germination time of approximately 17 to 25 days, with a percentage of sprouts as high as 90%. The combination of small and abundant seed sizes, high germination rates, and various distribution mechanisms allows this species to rapidly invade a habitat, especially in open areas [40].

Finally, the last species, *Sonchus arvensis*, is in the same family as *Sonchus asper*. This species is also known as a weed on agricultural lands [36]. Although its seed production is not as high as that of *S. asper*, its seeds are very easily spread by the wind and easily germinate [43]. This species also has allelopathic effects [44].

3.2. Potential for invasion of high-risk species into forest areas

The leading cause of plant invasion is the absence of factors that naturally control invasive plant populations [45]. In the absence of natural enemies, these species can grow and reproduce without disturbance [46]. This phenomenon is also supported by small seed size, abundance, easy distribution, high germination rates, and fast growth [47]. Apart from the inherent characteristics of these IAPS, habitat conditions also determine their rates of invasion. For example, a study on the spread of *Cestrum aurantiacum* in a remnant forest in Cibodas Botanic Garden [11] found that at least two factors supported its spread: the characteristics of the species and the environmental conditions that support the growth

and distribution of the species. Specifically, ecological conditions play a crucial role in the invasion process. [3] mentioned that habitat conditions also support the spread of IAPS, such as usually disturbed areas with low species diversity rates.

Although some IAPS are resistant to shade, most require a high intensity of sunlight and thus tend to grow in open areas [9]. In particular, Junaedi [48] found that the distribution of *Cestrum aurantiacum* was significantly related to light intensity. Specifically, the light intensity was higher at the location of species occurrence than that in the plot without the species. Therefore, invasive species populations are generally more abundant in open areas than in shaded locations. This information relates to this study as most of these plant species occur in cultivated areas (CBC buffer zone) rather than forest areas (Gunung Gede Pangrango National Park), as the population mostly exists in cultivated areas (Fig. 1). This occurrence also increases the ease of access of obtaining species that grow close to the settlements.

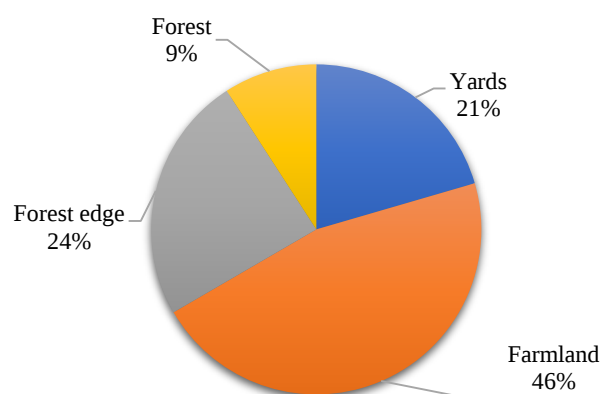


Figure 1. Source of utilized potential Invasive Alien Plant Species (IAPS).

Concerning the potential of invasion in tropical forest areas, [46] stated that the primary key to invasion occurrence in forest areas depends on canopy cover. Specifically, if the canopy cover is maintained, the site will be more resistant to invasion. For example, studies on the spread of invasive *Merremia peltata* in Bukit Barisan Selatan National Park showed that this species is more abundant in fragmented forests than in preserved forest areas [49]. Thus, it is generally assumed that well-managed protected areas, especially mountainous areas with a high level of species diversity, can withstand plant invasion [2]. Therefore, although the results of the WRA assessment indicate that certain species have a high potential for invasion, as long as the condition of the TNGP forest area is maintained, it is unlikely that these species will invade.

3.3. Efforts to control the population of potentially invasive alien plant species

Although the potential for invasion is low, it is still necessary to control the species spread in the CBR, not only in forest areas but also in cultivated areas. Management options can be adopted from research concerning the management of the invasive species *C. aurantiacum* [50]. Several options can be applied in this study, including eradication, containment, bio-control, harvesting, and doing nothing. Based on the literature, even though this study did not conduct an assessment process to determine which action was most appropriate for the application, because these IAPS are utilized, harvesting is arguably the most suitable management option. Further, harvesting can simultaneously be performed with containment, enabling the plant population to be controlled without further spread. Containment is a deliberate action that prevents the formation and reproduction of species outside a predetermined area [51]. Containment is the best management option when eradication is not feasible or has unexpected side effects [50].

Containment can be performed alongside harvesting activity by the community as a population control method in the locations the species spread. For species in cultivated areas (buffer zone), harvesting activities can be maximized and even commercialized. Some of these species have economic

value and are usually traded by the community. Similarly, several species in forest areas have a high potential as a source of food, medicine, or firewood. For example, *Chimonobambusa quadrangularis* has the potential to be used as a source of prebiotics [52], *Calliandra callothyrsus* as wood energy [53], or *Passiflora edulis* as a source of fruit [17]. Moreover, harvesting is a feasible management option because the species are mostly herbaceous plants and shrubs, making them easier to harvest than trees (Fig. 2).

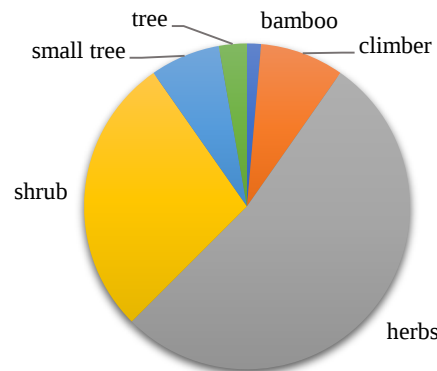


Figure 2. Lifeform of utilized potentially Invasive Alien Plant Species (IAPS).

Rai and Scarborough [54] stated that introduced species have already become part of the ecosystem, providing direct and indirect benefits. van Steenis and van Steenis-Kruseman [24] found many exotic species were introduced to the Cibodas mountain area around the 1800s. From the time the species was introduced to the present day, the period has undoubtedly made the species considered part of the community's life in the CBR area. Therefore, collaboration with the community on the management of potentially IAPS is needed, so the invasion risk of these species can be controlled, and the community can still benefit from these species' existence.

In this study, the WRA was used as a pre-assessment to determine the risk level and rapidly assess a large number of species at no cost. However, suppose there is a massive spread of potentially IAPS within the forest area. In that case, we must assess the invasive rate using post-border risk management [55], which can evaluate the real invasion risk by calculating the level of invasiveness, impact, and potential distribution of the species. Nevertheless, the method used herein determined a comparative risk value of every IAPS to formulate the most feasible management [55].

4. Conclusion

Based on the WRA assessment, 70 of the 72 utilized alien species have a high risk of invasion. Depending on their lifeform, which was dominated by herbaceous plants, and the species source, which was mostly cultivated areas (buffer zone), the invasion potential of these species in the TNGP forest area (CBC core zone) is low. However, the most suitable way to prevent potential invasion is to maintain the forest areas as unsuitable habitats for IAPS by preventing forest areas from fragmentation, maintaining canopy cover, and preserving a high diversity of plant species. The recommended management option for controlling the population based on the results of the WRA and the current utilization activity is a combination of harvesting and containment. By implementing these management options, the community can continue to utilize these species while controlling their populations.

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