BIODIVERSITAS
Volume 23, Number 6, June 2022
Pages: 3156-3165

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d230643

Diversity, risk and management feasibility of invasive alien plants in the border zone of Sicike-cike Nature Tourism Park, North Sumatra, Indonesia

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Manuscript received: 9 May 2022. Revision accepted: 28 May 2022.

Abstract. *Huda MK, Pasaribu N, Syamsuardi, Siregar ES. 2022. Diversity, risk and management feasibility of invasive alien plants in the border zone of Sicike-cike Nature Tourism Park, North Sumatra, Indonesia. Biodiversitas 23: 3156-3165.* Invasive alien species (IAS) threaten native ecosystems and biota either directly or indirectly. Once colonizing, invasive plant species tend to dominate a landscape, hindering other native vegetation from growing. Thus, the invasion of alien plant species needs attention moreover in protected areas such as Nature Tourism Park (Taman Wisata Alam/TWA) Sicike-cike, Dairi District, North Sumatra, Indonesia. Besides its importance for nature conservation, TWA Sicike-cike is culturally essential for Pakpak Dairi ethnic community as well as economically for ecotourism. Yet, anecdotal evidence showed the presence of several invasive alien plants around the park. This study aimed to investigate the diversity and composition of invasive alien plants within the vegetation community in TWA Sicike-cike and to assess the risk value and management feasibility of the IAS. Purposive sampling using line transect method was conducted to collect data with a total of 120 observation plots established along 6 transects. Risk value was assessed based on invasiveness, impact and potential distribution. Management feasibility was assessed based on cost, current distribution and persistence. The results showed that Asteraceae was the most dominant family of invasive plants in the studied area with four species. At the species level, *Imperata cylindrica* was invasive alien plant species with the highest important value index (IVI) of 57.65% and a high-risk value of 235.8, followed by other species including *Ageratum conyzoides, Chromolaena odorata, Clidemia hirta* and *Melastoma malabathricum*. In terms of management feasibility, the existence of *I. cylindrica* is recommended for direct eradication, while other IAS management recommendations, included monitoring and area protection for further invasion by the species.

Keyword: Border of Sicike-cike Natural Park, feasibility index, invasive alien plant species, risk index

INTRODUCTION

Indonesia is one of the countries with the highest biodiversity in the world. Biodiversity can be identified from the vegetation composition and structure as well as the diversity of animals living in an area. Biodiversity needs to be preserved for future generations, yet it is increasingly threatened by various factors, one of which is invasive alien species (IAS). An invasive alien plant is defined as a non-native plant species from other regions or countries that could grow rapidly and dominate an area, thus causing negative effects, including causing environmental damage or endangering humans, animals, plant health, and the composition of forest ecosystems (Rai 2021). Nowadays, almost every type of ecosystem on the Earth is affected by the presence of IAS, contributing to species extinction, especially in the island ecosystem (Macinis-Ng et al. 2021).

Invasive plants potentially threaten native biota and affect ecosystems, either directly or indirectly. An invasive alien plant forms relatively large new colonies of its offspring, thus negatively affecting the invaded ecosystem. Invasive alien plants can harm native biodiversity especially, the local species, by occupying the habitat area, utilizing environmental resources (nutrients, light and water) and dominating the vegetation structure and composition. Eventually, the diversity and abundance of native vegetation decrease due to being replaced by invasive alien plants that have superior competitive abilities (Hughes 2017). Invasive alien plants have special characteristics that are able to make them spread rapidly and aggressively and compete with native flora and fauna, forming dense populations, thus interfering with the natural development of biotic communities (Graebner et al. 2012; Yudaputra 2020).

Invasive alien plants colonize an area by taking advantage of the decreased resources that follow habitat degradation in which limited native species could grow and survive. In forest ecosystems, IAS might rapidly occur in deforested and degraded forests, yet not all of them are able to reach the interior of the forest with relatively intact canopy cover, and most of the invasive alien plants are found in forest exteriors or in forest gaps (Junaedi and Dodo 2014). Besides habitat degradation, the spread and formation of invasive alien species are further facilitated by climate change either at site scale and global scale. In terms of length of invasion time, some species show rapid invasion, while others may take a longer period of time.

Invasive alien plants can alter soil's physical and chemical properties, nutrient cycles, hydrology and disturbance regime of the invaded ecosystem. This can seriously affect the availability of resources both directly and indirectly. In addition to reducing the availability of ecosystem resources, many invasive alien plants become the physical barriers that inhibit the formation of native species propagules. This can occur when native propagules including trees must penetrate the thick layer of roots and rhizomes below the ground or the dense canopy above the ground to establish a foothold. In the case of native species that are successful in growing and surviving within an area where invasive alien plants occur, the intense competition between the invasive alien plants and native species may cause reduced fitness and growth rates of the native plants. This condition poses a serious challenge for natural and artificial regeneration in natural ecosystems invaded by invasive alien plants (Jose et al. 2013).

An example of invasive plant species that harms other plants due to competition for nutrients is *Chromolaena odorata*. This species originated from tropical America and was to be common in Asia in the early twentieth century. This plant has negative effects on native plants through several mechanisms such as changing the soil microbial communities (Rizali et al. 2019). Other invasive alien plant species are *Acacia auriculiformis* and *A. ringnata*, originating from Australia and having disturbed vegetation in other regions due to their ability to fix nitrogen. These species can easily colonize disturbed forests, particularly those susceptible to repeated droughts and fires. Over time, these species convert the habitat into monospecific stands (Minteer et al. 2020).

Invasive alien plant species cause danger to their invaded area because they can adapt rapidly to their new environment, moreover in protected areas. *Taman Wisata Alam* (Nature Tourism Park) Sicike-cike or so-called TWA Sicike-cike is a protected area in Dairi District, North Sumatra Province, Indonesia which is designated as a natural tourism destination and also serves as an important area for local communities to carry out their rituals or maintain their beliefs (Huda et al. 2020). *Pakpak Batak* ethnic people are adherents of the sacred Sicike-cike forest. They generally use certain sites for their religious activities by believing that Sicike-cike is the origin of the *Pakpak Batak* ancestors known as *Silima Sulang Sipitu Marga* (Situmorang and Simanjuntak 2015). Due to its importance in terms of biodiversity conservation and socio-cultural aspect, this research is aimed to investigate the diversity and composition of invasive alien plants within the vegetation community in TWA Sicike-cike and to assess the risk value of the IAS so that recommendations for species management in the buffer zone of TWA Sicike-cike can be formulated.

MATERIALS AND METHODS

Study area and period

The study was conducted at the buffer (border) zone of the Sicike-cike Nature Tourism Park, North Sumatra (Figure 1). Sicike-cike Nature Tourism Park was designated as a conservation area based on the Decree of the Minister of Forestry No.78 / Kpts-II / 1989 dated 7 February 1989 with an area of 575 ha. The environmental condition recorded during the survey was air temperature (19-23ºC), relative humidity (88-98%), altitude (1300-1400 m a.s.l), and soil pH (4.5-6.0) with a cool climate. *At malayanum* was documented as the primary indicator of typical vegetation in the study site (Huda et al. 2020). This area is geographically located at 02º35´-2º41' N and 98º20´-98º30´ E.

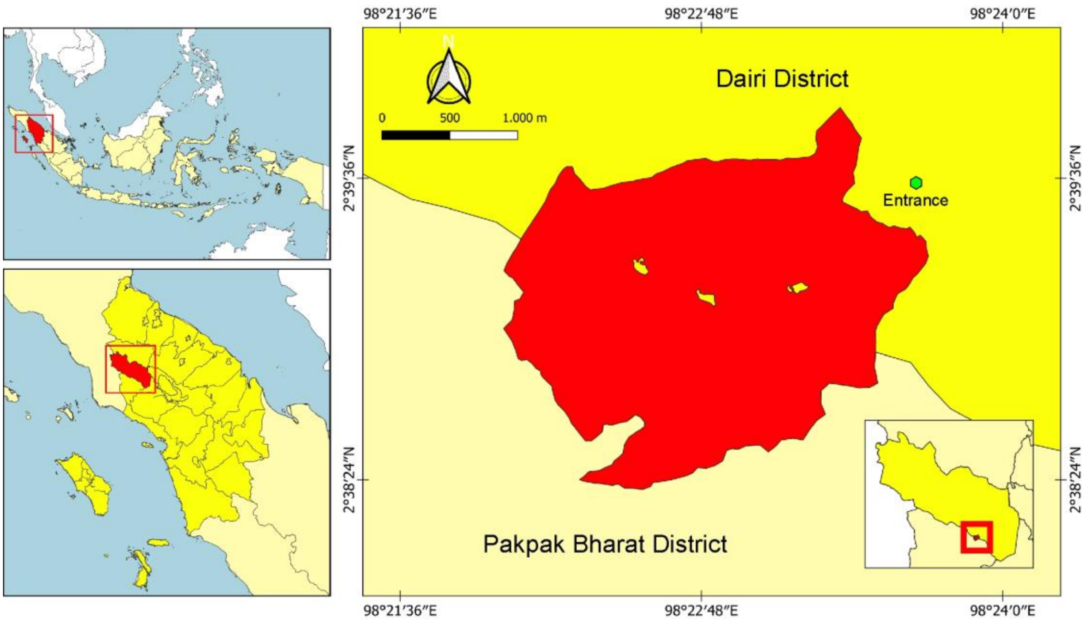

Figure 1. Map of the study area in TWA Sicike-cike, Dairi District, North Sumatra Province, Indonesia

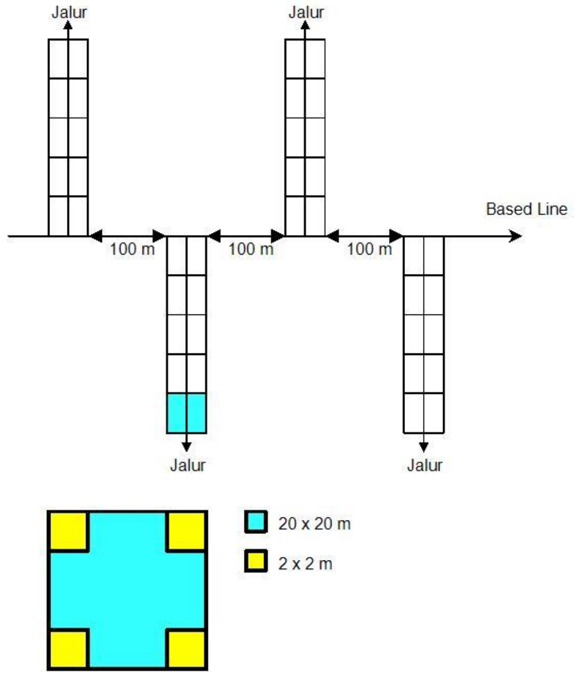

Figure 2. Diagrammatic overview of the line-transect method and observation plot for data collection

Data collection

Observation plots for data collection were determined through purposive sampling using line-transect method (Figure 2). There were 6 line transects and a total of 120 plots were established. The observation plot in each line-transect consisted of large plots of 20x20 m in which there were 4 observation plots of 2x2 m placed in each corner of the large plot. The large plot (20x20 m) was placed in 5 plots of 100 m long line-transect on the right and left in alternating positions with a distance of 100 meters between the transects. All plants considered invasive were observed in the form of herbs, shrubs, ferns, palms, grasses, and others that are not classified as trees and non-vascular vegetation plants such as mosses. The determination of invasive alien species was done by looking at the invasive alien plant database of http://www.issg.org, http://www.cabi.org, or based on government websites regarding invasive alien plants such as https:/ /www.nrcs.usda.gov, hosted by the Republic of Indonesia. The invasive alien plants also referred to Regulation of Minister No. 94 of 2016 regarding the manual of invasive alien plants in Indonesia and the book of 75 invasive alien plants in Indonesia (Setyawati et al. 2015; Tjitrosoedirdjo et al. 2016).

Data analysis

The vegetation data collected were then analyzed for Relative Density (R_D), Relative Frequency (R_F), and Important Value Index (IVI) using the formulas suggested by Sidabukke et al. (2021) as follows:

Density

$$\text{Absolute Density (D)} = \frac{\text{Number of individual of one species}}{\text{Sample plot area / observation plot}}$$

$$\text{Relative Density } (R_D) = \frac{\text{absolute density of one species}}{\textit{total absolute density of all species}} \times 100\%$$

Frequency

$$\text{Absolute frequency (F)} = \frac{\textit{number of plot inhibited by a speciess}}{\textit{total observation plots}}$$

$$\text{Relative frequency } (R_F) = \frac{\textit{frequency of a species}}{\textit{frequency of total of all species}} \times 100\ \%$$

Important Value Index

$$IVI = R_D + R_F$$

The risk value and management feasibility of the invasive alien plants were determined based on the international standards followed Tjitrosoedirdjo et al. (2016). The risk value was obtained by multiplying the criteria for invasiveness, impact, and distribution potential as follows:

Risk = Invasiveness × Effect × Distribution potential

The results of the analysis were then categorized into intervals as listed in Table 1.

The feasibility of plant management was examined based on three criteria, namely management cost, current distribution, and persistence with the value was calculated as follows:

Feasibility of management = management cost x current distribution x persistence

Management costs included the detection/surveillance/ monitoring costs, eradication costs in the field, as well as costs needed for strengthening capacity and education needs. Current distribution pays attention to the invasive area of the invasive alien plants. Meanwhile, persistence refers to the period during which the results can persist. After the score for each criterion was determined, all the criteria were multiplied to obtain the management feasibility value. The determination of the management feasibility value refers to the intervals listed in Table 2.

Following the determination of the risk value and management feasibility, guidance on strategic actions for appropriate management of invasive alien plants was developed based on the matrix as provided in Table 3.

Table 1. Category of risk of invasive alien plants based on frequency interval and risk value

Interval of frequency	Risk value of invasive plants	Risk of invasive plants
80-100%	>192	Very high
60-80%	<192	High
40-60%	<101	Medium
20-40%	<39	Low
0-20%	<13	Ignored

RESULTS AND DISCUSSION

We recorded 15 species of invasive alien plants (IAS) in the observation plots which belong to 8 families with a total of 1,385 individuals (Figure 3). Based on their life/habitus form, 5 species belong to herbs, 2 species belong to shrubs, 2 species belong to ferns, 4 species belong to grass, and 1 species belongs to climbing herbs. The dominant families were Asteraceae and Poaceae with 4 and 3 species, respectively. According to Zida et al. (2020), Poaceae, Asteraceae, Fabaceae, and Cyperaceae are families that have a large number of seeds, suggesting that they are being easily widespread in an area.

Asteraceae, also called Compositae, is a widely distributed flowering plant group in the world with 32.913 species belonging to 1.911 genera and 13 subfamilies (Rustaiyan and Faridchehr 2021). Asteraceae can be widespread and dominate a habitat because it has a breeding system that tends to be xenogamous so that it produces genetically varied offspring with favorable characters. Asteraceae has a large number of propagules, which that can adapt well to various habitats, and seed dispersal by wind causes this invasive plant species to spread widely and dominate the habitat (Syamsuardi et al. 2016). Asteraceae is a family of invasive alien plants with a higher reproductive capacity and expansion ability than other plant families (Wagh and Jain 2018). For example, Asteraceae is considered the family with the highest invasive alien plant seeds in China with 17.93% of the species from this family classified as cosmopolitan which have successfully spread to many environments due to its high fecundity (reproductive ability) features (Wang et al. 2016).

Table 2. Category of management feasibility value of invasive alien plants based on risk and frequency value

Interval of frequency	Risk value of invasive plants	Risk of invasive plants
80-100%	113+	Insignificant
60-80%	<113	Low
40-60%	<56	Medium
20-40%	<31	High
0-20%	<14	Very High

Table 3. Matrix of strategic management actions of invasive alien plants

Invasive Alien Plants Risk	Feasibility of Management: Insignificant >113	Low 56-112	Medium 31-55	High 14-30	Very High <14	
Insignificant <14	Limited action	Limited action	Limited action	Limited action	Monitor	
Low 15-38	Limited action	Limited action	Limited action	Monitor	Monitor	
Medium 39-101	Site management	Site management	Site management	Site Protection	Spread prevention	ALERT
High 102-192	Invasive alien plants management	Invasive alien plants management	Site Protection	Spread prevention	Destroying infestation	
Very High >192	Invasive alien plants management	Site protection and invasive alien plants management	Spread prevention	Destroying infestation	Eradication	

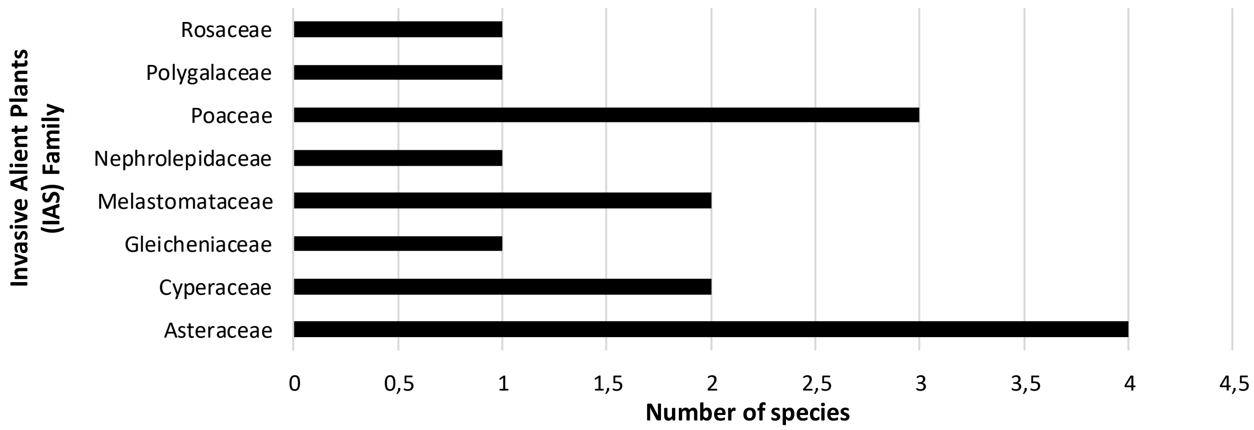

Figure 3. The composition of invasive alien plants in the observation plots in the TWA Sicike-cike, North Sumatra, Indonesia

In addition to Asteraceae, Poaceae was another plant family with the most species found in the studied area. Poaceae reproduces very quickly either through generative or vegetative reproduction. Poaceae (grasses) is arguably the most successful plant family in terms of its global occurrence in almost all ecosystems, its ecological dominance in many ecosystems, and its high species richness (Linder et al. 2018). The economic and ecological significance of the Poaceae family causes this family to be widely distributed in the world. They have long been known as a grasses group in nature with about 12,000 species from 780 genera (Christenhusz and Byng 2016). Furthermore, Poaceae can also spread quickly because the seeds are light and easily carried by the wind. In addition, the root system of rhizomes (in the soil) and stolons (above the soil) causes high expansion capabilities and can reach far areas.

Table 4 shows that *Imperata cylindrica* had the highest IVI (57.65%) compared to other invasive plants. This indicates that *I. cylindrica* has high adaptability and wide distribution. It was further proven by the finding of 609 individuals, or a high relative density that reached 43.97%. However, its distribution pattern tended to be grouped as indicated by the relative frequency of the species with only 13.68%, while other plants were rarely found within the group. A large number of *I. cylindrica* individuals are in the area because they can reproduce vegetatively and generatively. Meanwhile, its grouping nature, which is rarely found in other species, is caused by its allelopathy. Salim et al. (2020) reported that *I. cylindrica* contains allelochemical compounds particularly in the root which may contribute to its invasiveness and extreme competitiveness.

Environmental factors also contributed to the adaptation of *I. cylindrica* to the studied area in the buffer zone of TWA Sicike-cike which had open shade, soil pH of 4-5.9, the temperature of 23-27°C, and humidity of 77-85%. This is in accordance with the statement by Ahmad et al. (2020) that *I. cylindrica* is tolerant of various soil conditions, including variations in fertility, organic matter, and moisture. In addition, *I. cylindrica* can adapt well to nutrient-poor soils, tolerate dry soil, and has genetic adaptation to fire (Holzmueller and Jose 2012). This shows that *I. cylindrica* is superior as indicated by its high IVI as a dominant species that have the greatest importance in the community and great adaptability in the habitat.

Based on Table 4, the second-highest IVI was *Nephrolepis biserrata* (31.86%) and followed by *Dicranopteris linearis* (30.55%). In contrast to *I. cylindrica*, *N. biserrata* tended to be evenly distributed with R_F of 24.79% although fewer individuals were found with 98 (R_D = 7.08%). Meanwhile, *D. linearis* had 281 individuals (R_D = 20.29%) with relative frequency of only 10.26%. Both types are classified as ferns which can be identified by two main parts, namely vegetative organs (roots, stems, and leaves) and generative organs (spores, sporangium, antheridia, and archegonia). Ferns have a vascular system and reproduce by producing spores. This trait allowed *N. biserrata* to be widespread in the buffer zone of TWA Sicike-cike. Furthermore, *D. linearis* produces many individuals, so that it can grow as tall as adults and form shrubs. Although the control of this plant it can be done manually by hand, but it is somewhat difficult because when the plants break off, they leave plant parts in the soil which can grow back (Yang et al. 2021).

Table 4. Vegetation composition of the invasive alien plant species in the studied area of TWA Sicike-cike, North Sumatra, Indonesia

Species	Family	Origin	Life-form	Dr	Rf	IVI
Imperata cylindrica	Poaceae	America and Caribia	Grass	43.97%	13.68%	57.65%
Nephrolepis biserrata	Nephrolepidaceae	Tropical Africa	Fern	7.08%	24.79%	31.86%
Dicranopteris linearis	Cyperaceae	Pacific islands	Fern	20.29%	10.26%	30.55%
Rhynchospora corymbosa	Cyperaceae	Tropical America (Florida)	Grass	7.29%	5.98%	13.28%
Clidemia hirta	Melastomataceae	South America	Shrub	2.89%	9.40%	12.29%
Rubus moluccanus	Rosaceae	Himalayas. Malaysia to Australia. Solomon Islands. New Caledonia and Fiji	Fern	1.52%	10.26%	11.77%
Chromolaena odorata	Asteraceae	Central and South America	Shrub	2.67%	8.55%	11.22%
Polygala paniculata	Polygalaceae	Tropical America from Mexico to Brazil	Shrub	5.34%	5.13%	10.47%
Paspalum conjugatum	Poaceae	Tropical America	Grass	5.05%	3.42%	8.47%
Crassocephalum crepidioides	Asteraceae	Tropical Africa	Shrub	2.31%	2.56%	4.87%
Melastoma malabathricum	Melastomataceae	Asia	Shrub	0.51%	2.56%	3.07%
Kyllinga nemoralis	Poaceae	East Africa. Southeast Asia	Grass	0.58%	0.85%	1.43%
Ageratum conyzoides	Asteraceae	Central America & Caribia	Shrub	0.36%	0.85%	1.22%
Emilia sonchifolia	Gleicheniaceae	Tropical Asia and Africa	Shrub	0.07%	0.85%	0.93%
Erechtites hieraciifolius	Asteraceae	China and Southeast Asia	Shrub	0.07%	0.85%	0.93%

Notes: Dr: Relative density, Fr: Relative frequency, IVI: Important value index

One of the parameters to show the pervasiveness of invasive alien plant species in the vegetation community is to use an important value index, although it cannot show the risk value and management feasibility of the invasive species. Indirectly, the risk value and management feasibility can involve data on the density and frequency of the invasive alien species. For example, in determining the invasiveness, one can look at individual characteristics, while on the management feasibility for the current distribution question, one can look at the range of types or the frequency of the plants at the observation site, resulting in risk and management feasibility values that are not too distinguishable (Table 5 and 6).

Based on Table 5, the risk values of invasive species based on their invasiveness, impact and potential distribution are presented. The invasiveness parameter indicates establishment, reproduction and spread, while the impact parameter indicates the potential impact of the weeds. The questions analyzed relate to land-use systems such as decreased stability of desired plants, decreased production of desired species, decreased quality of ecological services of the landscape, weeds inhibiting activities of humans/animals/other plants, effects of weeds on health animals or animals, and a large positive/negative influence on environmental health. The potential distribution only looks at how likely the landscape of be invaded by the invasive plants.

Imperata cylindrica was classified as a high-risk IAS with a score of 235.8 as the result of an invasiveness value of 8.0, the impact value of 7.4, and the potential distribution value of 4.0. Meanwhile, concerning its management feasibility, the species also had a very high score of 1.5 (Table 6). Therefore, referring to the strategic action matrix of invasive alien plant management presented in Table 3, *I. cylindrica*, or locally known as *alang-alang*, is recommended to be eradicated. *I. cylindrica* is grass with a height that can reach 1 m (Tjitrosoedirdjo et al. 2016). This species is native to East Africa and Southeast Asia which has now spread widely and has become invasive in various countries in the world. In Java, this species is often found in cultivation areas, sometimes in conservation areas. This species generally grows in plantations and has an impact on tea plantations (Setyawati et al. 2015). It has the ability to compete effectively for water and nutrients, spread, and survive through the production of seeds and rhizomes. It can also survive a wide range of environmental conditions and allelopathic effects, as well as pyrogenic characteristics which allow it to exclude native species and dominate large areas.

Imperata cylindrica is one of the pioneer plants that can reproduce vegetatively and generatively in open locations. The seeds are easy to disperse and need simple abiotic variables to grow, such as a temperature range of 19-27°C with an optimum temperature of 23°C. The species has a wide tolerance of various environmental conditions (often so-called cosmopolitan plants), and it can live in tropical and subtropical climates (MacDonald 2010). The high-risk value obtained by *I. cylindrica* can be caused by its easiness of living among dense vegetation or other dense weeds. This occurs because *I. cylindrica* rhizomes can release allelopathic compounds around the place where it grows. Because it can reproduce generatively and vegetatively, *I. cylindrica* can increase its population quickly and spread in the area it inhabits. This species is an enemy for farmers because of the difficulty and high cost of controlling it, which causes tremendous losses due to decreased crop yield (Syahrinudin et al. 2020). In addition, *I. cylindrica* is considered a problematic plant in natural areas, causing serious economic and environmental damage (Soerjani 1983).

Other invasive alien plant species categorized as high risk were *Clidemia hirta*, *Melastoma malabathricum*, and *Chromolaena odorata*. The species of *C. hirta* is a very dangerous invasive alien plant because it has allelopathic compounds that can inhibit the growth of native species. In addition, *C. hirta* can spread its flowers quickly throughout the year and is more abundant outside its natural habitat than in its natural habitat. *C. hirta* is an understory-type plant that has high adaptability because it is able to grow optimally at low altitudes up to 1000 m above sea level with open and moist environmental conditions and soils that have high humus content (Ismaini 2015).

Table 5. Risk index and category of IAS plants in the buffer zone of TWA Sicike-cike, North Sumatra, Indonesia

Species	Parameters			Risk index (R)	Risk category
	Invasiveness (IV)	Impact (I)	Potential distribution (PD)		
Ageratum conyzoides	5.3	2.6	0.5	7.0	Insignificant
Chromolaena odorata	8.0	4.2	2.0	67.4	Medium
Clidemia hirta	12.7	6.4	2.0	162.8	High
Crassocephalum crepidioides	5.3	1.1	0.5	2.8	Insignificant
Dicranopteris linearis	8.7	5.3	2.0	91.2	Medium
Emilia sonchifolia	2.7	3.2	0.5	4.2	Insignificant
Erechtites hieraciifolius	4.7	2.1	0.5	4.9	Insignificant
Imperata cylindrica	8.0	7.4	4.0	235.8	Very high
Kyllinga nemoralis	5.3	4.2	0.5	11.2	Insignificant
Melastoma malabathricum L.	6.7	5.8	1.0	38.6	Low
Nephrolepis biserrata	8.0	3.2	4.0	101.1	High
Paspalum conjugatum	5.3	2.6	1.0	14.0	Low
Polygala paniculata	7.3	2.1	2.0	30.9	Low
Rhynchospora corymbosa	7.3	4.2	1.0	30.9	Low
Rubus moluccanus	7.3	4.2	2.0	61.8	Medium

Table 6. Management feasibility index and category of IAS plants in the buffer zone of TWA Sicike-cike, North Sumatra, Indonesia

Species	Parameters Control Cost (CC)	Actual Distribution (AD)	Persistence (P)	Feasibility Index (F)	Feasibility category
Ageratum conyzoides	3.3	0.0	4.5	0.6	Very high
Chromolaena odorata	5.3	1.3	6.4	42.4	Medium
Clidemia hirta	5.3	1.3	5.5	36.4	Medium
Crassocephalum crepidioides	4.7	0.1	3.6	1.4	Very high
Dicranopteris linearis	5.3	2.5	4.5	60.6	Low
Emilia sonchifolia	2.7	0.0	2.7	0.3	Very high
Erechtites hieraciifolius	2.7	0.0	2.7	0.3	Very high
Imperata cylindrica	4.0	0.1	4.5	1.5	Very high
Kyllinga nemoralis	2.7	0.0	2.7	0.3	Very high
Melastoma malabathricum	4.7	0.9	3.6	15.6	High
Nephrolepis biserrata	6.0	3.3	6.4	127.3	Insignificant
Paspalum conjugatum	4.7	0.9	4.5	19.4	High
Polygala paniculata	4.7	1.3	3.6	21.2	High
Rhynchospora corymbosa	5.3	1.3	3.6	24.2	High
Rubus moluccanus	5.3	1.7	4.5	40.4	Medium

Table 7. Recommendation of IAS plants management

Species	Risk category	Feasibility Category	Recommendation of management
Ageratum conyzoides	Insignificant	Very high	Monitor
Chromolaena odorata	Medium	Medium	Site management
Clidemia hirta	High	Medium	Site protection
Crassocephalum crepidioides	Insignificant	Very high	Monitor
Dicranopteris linearis	Medium	Rendah	Site management
Emilia sonchifolia	Insignificant	Very high	Monitor
Erechtites hieraciifolius	Insignificant	Very high	Monitor
Imperata cylindrical	Very high	Very high	Eradication
Kyllinga nemoralis	Insignificant	Very high	Monitor
Melastoma malabathricum	Rendah	High	Monitor
Nephrolepis biserrata	High	Insignificant	Invasive alien plants management
Paspalum conjugatum	Rendah	High	Monitor
Polygala paniculata	Rendah	High	Monitor
Rhynchospora corymbosa	Rendah	High	Monitor
Rubus moluccanus	Medium	Medium	Site management

In the studied area of TWA Sicike-cike, *C. hirta* tended to grow in a group. In this case, the distance from the road and the intensity of light did not affect the distribution of *C. hirta* individuals because they can adapt well even under shade. In some habitat conditions with dense canopy cover, this plant species can survive and adapt optimally. In an open condition, this plant species will tend to grow tall quickly but not form colonies. Meanwhile, in a shaded condition, *C. hirta* will grow slowly but form a colony in high density. Based on its original ecology, *C. hirta* is a fast-growing and shade-tolerant pioneer shrub that grows in primary forests and along steep slopes. As an invasive alien plant, this plant grows in areas where there are gaps between trees in forests and other disturbed areas, growing to form dense vegetation and almost impenetrable by all native vegetation due to the large size of the leaves. As an invasive alien plant species, *C. hirta* has a high reproductive and dispersal mechanism (Le et al. 2018). Its fruit production is abundant, and seeds are dispersed mainly by birds but can also be carried out by other animals.

Clidemia hirta belongs to the weed category that is commonly found in agricultural lands, ex-mining areas, open areas, and roadsides. This plant easily grows in such areas because of several factors, such as having an aggressive nature with high germination ability and being shade tolerant. In the buffer zone of TWA Sicike-cike, *C. hirta* grew in the shade and was widely distributed in the observation plots. They produced a large number of fruits with an average height of around 50 cm. Many invasive alien plant species produce abundant fruits and widely distributed seeds that can survive in the soil for many years (Moracova et al. 2015).

Melastoma malabathricum (syn. *Melastoma sanguineum, Tibouchina urvilleana,* and *Melastoma candidum*) is also an invasive alien species with a high-risk value found in the TWA Sicike-cike. This species was mostly found with shrub stature reaching 1.5 m and was flowering although there were only 7 individuals in the observation plots. *M.*

malabathricum is considered a dangerous invasive alien species, and in Indonesia, this species is classified as 75 dangerous invasive alien plant species (Tjitrosoedirdjo et al. 2016). It is now widespread throughout East, South and Southeast Asia into Pacific Islands.

Globally, *M. malabathricum* is considered a dangerous weed. This is because its berries and small seeds might contaminate agricultural products harvested from the same environment. This species has also become a problematic weed in rubber plantations in Indonesia, Malaysia, Sri Lanka, and Western Africa. *M. malabathricum* is an Indonesian native species that is spread throughout the region as a pioneer plant and also as a shrub on the edge of forests and roads. Nonetheless, this species does not appear to dominate the vegetation in secondary and primary forests even though it can grow under shade (Setyawati et al. 2015). In Malaysia, *M. malabathricum* grows along highways. Since its fruit is favored by birds, *M. malabathricum* can quickly colonize open lands (Master et al. 2020).

A total of 37 individuals of *C. odorata* were found in the buffer zone of TWA Sicike-cike. The plant height reaches 2 m, and the flowers are white and small so that they are easily scattered by the wind. *C. odorata* is a perennial herb that forms dense shrubs up to 1.5-2 m high, sometimes reaching a height of 6 meters. The stems are freely branched with lateral branches developing in pairs from the axillary buds. Older stems are brown and woody near the tip and young shoots are green and succulent. The root system is fibrous and does not penetrate more than 20-30 cm in most soils. The flowers are white or pale bluish-purple and form a mass that covers the entire surface of the bush. The seeds are small, 3-5mm long, ~1mm wide, and weigh about 2.5 mg/seed.

Similar to the two species mentioned above, *C. odorata* is one of the problematic tropical weeds belonging to the Asteraceae family. The native range of *Chromolaena* is the Americas, extending from Florida (USA) to northern Argentina. Currently, it is widespread in tropical and subtropical areas from the west, central and southern Africa to India, Sri Lanka, Bangladesh, Laos, Cambodia, Thailand, southern China, Taiwan, Indonesia etc. (Vaisakh and Pandey 2012). This species can grow very fast and is able to dominate the area it inhabits because this species is very competitive in capturing light and nutrients (Xu et al. 2019). It produces a lot of seeds and grows well on a variety of soil types. In Indonesia, this species is mostly found in the lowlands from 0 to 500 m asl (Sutomo et al. 2020).

In terms of management feasibility, 6 species belong to a very-high category, 4 species in the high category, 3 species in medium category, and one species belong to an insignificant category. Feasibility is related to the cost of control by looking at how easy it is to detect. It also includes accessibility and stakeholder cooperation in controlling invasive alien plants. The difference between the current distribution and the potential distribution lies in the real distribution in the field by looking at how widely invasive alien plants are currently scattered in the area controlled. About 20-40% of *N. biserrata* were found in the observation plot in the TWA Sicike-cike border area. However, because the species was not found in the study area, the species received a score of 2 for the current distribution. This score reflects the percentage of land invaded by alien plants and is part of the overall land-use system. Previous research documented 10 invasive alien species in Pangandaran Nature Reserve and 5 of them had high IVI (Hasbi and Rosleine 2020). In their research, management options recommended were based on the plant's risk and feasibility, namely *Tectona grandis* and *C. odorata* by managing the species, *Cynodon dactylon*, *M. malabathricum* and *Chrysopogon aciculatus* by managing the area, and *Fimbristylis monostachya* by monitoring.

In the studied area, one invasive plant species are recommended to be eradicated, namely *I. cylindrica* (Table 7). On the other hand, management of "protect sites" is recommended for *C. hirta*, "manage invasive plants" for *N. biserrata*, "manage sites" for *C. odorata* and *Dicranopteris linearis* and "monitoring" for other species. Eradication aims to destroy invasive alien plants (*I. cylindrica*) in the border area of TWA Sicike-cike. However, since *I. cylindrica* was not found in the core area and scored 0 in the management feasibility, a "standby" recommendation was given for this plant aimed at preventing the entry of this species into the core area. Several other things that must be done in this regard are continuous monitoring for invasion of alien species (e.g., nursery inspections) as well as training community awareness so that they can carry out early detection. Although *I. cylindrica* has not been found in the core area, it turns out that invasive alien species such as *A. conyzoides*, *C. odorata*, *C. hirta* were found around the river area which is directly adjacent to the study area. Allegedly, *M. malabathricum* has been found around the lake in TWA Sicike-cike. Protecting the site aims to prevent the spread of invasive alien plants into important sites within the TWA Sicike-cike which have high economic, social and ecological values to reduce the impacts of these plants. In addition, monitoring is similarly important to detect significant changes in the risk of invasive alien plant species.

ACKNOWLEDGEMENTS

This research was funded by Direktorat Riset dan Pengabdian Masyarakat (DRPM), Indonesian Ministry of Research, Technology and Higher Education (KEMENRISTEK DIKTI) under the scheme of *Penelitian Disertasi Doktor* year 2018 with proposal title 'Vegetation Analysis of Invasive Alien Plant Species around TWA Sicike-cike, Dairi District, North Sumatra'. The authors would also like to thank the Agency for Conservation of Natural Resources North Sumatra (BBKSDA-SU) for the official permit of the study.

REFERENCES

Ahmad KS, Wazarat A, Mehmood A, Ahmad MSA, Tahir MM, Nawaz F, Ahmed H, Zafar M, Ulfat A. 2020. Adaptations in *Imperata* *cylindrica* (L.) Raeusch. and *Cenchrus ciliaris* L. for altitude tolerance. Biologia 75: 183-198. DOI: 10.2478/s11756-019-00380-2.

Christenhusz MJM, Byng JW. 2016. The number of known plants species in the world and its annual increase. Phytotaxa 261 (3): 201-217. DOI: 10.11646/phytotaxa.261.3.1.

Graebner RC, Callaway RM, Montesinos D. 2012. Invasive species grows faster, competes better, and shows greater evolution toward increased seed size and growth than exotic non-invasive congeners. Plant Ecol 213: 545-553. DOI: 10.1007/s11258-012-0020-x.

Hasbi AM, Rosleine D. 2020. Risk assessment of invasive alien plant species in Pangandaran Nature Reserve, West Java, Indonesia. Eco Env Cons 26: S91-S99.

Holzmueller EJ, Jose S. 2012. Response of the invasive grass *Imperata cylindrica* disturbance in the Southeastern Forests, USA. Forest 3: 853-863. DOI: 10.3390/f3040853.

Huda MK, Pasaribu N, Syamsuardi, Siregar ES. 2020. Vegetation structure and composition in Taman Wisata Alam (TWA) Sicike-cike as ritual site for local community. J Phys: Conf Ser 1462: 0120150. DOI: 10.1088/1742-6596/1462/1/012050.

Hughes AC. 2017. Understanding the drivers of Southeast Asian biodiversity loss. Ecosphere 8 (1): e01624. DOI: 10.1002/ecs2.1624.

Ismaini L. 2015. Pengaruh alelopati tumbuhan invasif (*Clidemia hirta*) terhadap germinasi biji tumbuhan asli (*Impatiens platypetala*). Pros Sem Nas Masy Biodiv Indon 1 (4): 834-837. DOI: 10.13057/psnmbi/m010429.

Jose S, Singh HP, Batish DR, Kohli RK. 2013. Invasive Plant Ecology. CRC Press, Florida. DOI: 10.1201/b13865.

Junaedi DI, Dodo. 2014. Exotic plants in Halimun Salak Corridor: Micro-environment, detection and risk analysis of invasive plants. Biotropia 21 (1): 38-52. DOI: 10.11598/btb.2014.21.1.4.

Le C, Fukumori K, Hosaka T, Numata S, Hashim M, Kosaki T. 2018. The distribution of an invasive species, *Clidemia hirta* along roads and trails in Endau Rompin National Park, Malaysia. Trop Conserv Sci 11: 1-9. DOI: 10.1177/1940082917752818.

Linder HP, Lehmann CER, Archibald S, Osborne CP, Richardson DM. 2018. Global grass (Poaceae) success underpinned by traits facilitating colonization, persistence and habitat transformation. Biol Rev Camb Philos Soc 93 (2): 1125-1144. DOI: 10.1111/brv.12388

MacDonald GE. 2010. Cogongrass (*Imperata cylindrica*) - Biology, ecology, and management. Crit Rev Plant Sci 23 (5): 367-380. DOI: 10.1080/07352680490505114.

Macinis-Ng C, Mcintosh AR, Monks JM, Waipara N, White RSA, Boudjelas S, Clark CD, Clearwater MJ, Curran TJ, Dickinson KJM, Nelson N, Perry GLW, Richardson SJ, Stanley MC, Peltzer DA. 2021. Climate-change impacts exacerbate conservation threats in island systems: New Zealand as a case study. Front Ecol Environ 19 (4): 216-224. DOI: 10.1002/fee.2285.

Master J, Qayim I, Setiadi D, Santoso N. 2020. Autecology of *Melastoma malabathricum*, an invasive species in the Way Kambas National Park, Indonesia. Biodiversitas 21 (5): 2303-2310. DOI: 10.13057/biodiv/d210562

Minteer CR, Smith MC, Madeira P, Goosem C, Zonneveld R, Makinson J, Wheeler GS, Purcell M. 2020. Is biological control for earleaf acacia (*Acacia auriculiformis*) feasible in the United States? Biocontrol Sci Technol 30 (12): 1275-1299. DOI: 10.1080/09583157.2020.1833305.

Moravcova L, Pysek P, Jarosik V, Pergl J. 2015. Getting the right traits: Reproductive and dispersal characteristics predict the invasiveness of herbaceous plant species. PLoS ONE 10 (4): e0123634. DOI: 10.1371/journal.pone.0123634.

Rai PK. 2021. Environmental degradation by invasive alien plants in the Anthropocene: Challenges and prospects for sustainable restoration. Anthr Sci 1: 5-28. DOI: 10.1007/s44177-021-00004-y.

Rizali A, Hadi MS, Pudjianto P, Buchori D. 2019. A new trophic interaction between invasive weed, its biological control agent, and local insects: A case study of *Chromolaena odorata*. Biodiversitas 20 (4): 1006-1011. DOI: 10.13057/biodiv/d200410.

Rustaiyan A, Faridchehr A. 2021. Constituents and biological activities of selected genera of the Iranian Asteraceae family. J Herb Med 25: 100405. DOI: 10.1016/j.hermed.2020.100405.

Salim MAA, Linatoc AC, Jikan SS, Jamil S, Latif MS. 2020. Allelopathic effects of *Imperata cylindrica* aqueous extract on the germination of *Cucumis sativus* and *Lolium perenne*. Intl J Recent Technol Eng 8 (6): 2503-2508. DOI: 10.35940/ijrte.F8370.038620.

Setyawati S, Narulita S, Bahri IP, Raharjo GT. 2015. A Guide Book to Invasive Alien Plant Species in Indonesia. Research, Development and Innovation Agency, Ministry of Environment and Forestry, Bogor. [Indonesian]

Sidabukke SH, Barus TA, Utomo B, Delvian. 2021. The undergrowth composition and distribution in different forest area utilization. Biodiversitas 22 (12): 5255-5261. DOI: 10.13057/biodiv/d221203.

Situmorang ROP, Simanjuntak ER. 2015. Forest management through local wisdom of the community around the Sicike-cike Nature Park, North Sumatra. Widyariset 18 (1): 145-154. [Indonesian]

Soerjani M, Eussen HJJ, Tjitrosudirdjo S. 1983. *Imperata* research and management in Indonesia. Mt Res Dev 3 (4): 397-404. DOI: 10.2307/3673046.

Sutomo, Darma IDP, Iryadi R. 2020. The dissimilarity in plant species composition of savanna ecosystem along the elevation gradient on Flores Island, East Nusa Tenggara, Indonesia. Biodiversitas 21 (2): 492-496. DOI: 10.13057/biodiv/d210209

Syahrinudin, Denich M, Becker M, Hartati W, Vlek PLG. 2020. Biomass and carbon distribution on *Imperata cylindrica* grasslands. 21 (1): 74-79. DOI: 10.13057/biodiv/d210111.

Syamsuardi, Nurainas, Yuranti W, Yulianti W, Usman S. 2016. Floristic analysis of alien invasive plant species at some conservation areas in tropical forest of West Sumatra. Der Pharm Lett 8 (19): 237-245.

Tjitrosoedirdjo SS, Mawardi I, Tjitrosoedirdjo S. 2016. 75 Important Invasive Alien Plant Species in Indonesia. SEAMEO BIOTROP, Bogor. [Indonesian]

Tjitrosoedirdjo S, Setyawati T, Sunardi, Subiakto A, Irianto RSB, Garsetiasih R. 2016. Pedoman Analisis Risiko Spesies Asing Invasif (Post Border). FORIS Indonesia, Pusat Penelitian dan Pengembangan Hutan, Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia. [Indonesian]

Vaisakh MN, Pandey A. 2012. The invasive weed with healing properties: A Review on *Chromolaena odorata*. Int J Pharm Sci Res 3 (1): 80-83.

Wagh VV, Jain AK. 2018. Status of ethnobotanical invasive plants in western Madhya Pradesh, India. South Afr J Bot 114: 171-180. DOI: 10.1016/j.sajb.2017.11.008.

Wang C, Liu J, Xiao H, Zhou J, Du D. 2016. Floristic characteristics of alien invasive seed plant species in China. An Acad Bras Cienc 88: 1791-1797. DOI: 10.1590/0001-3765201620150687.

Xu Q-Y, Wang D, Quan G-M, Zhang J-E, Li R-H, Liu H. 2019. *Penisetum hydridum*'s potential for controlling invasive *Chromolaena odorata*. Sustainability 11: 5990. DOI: 10.3390/su11215990.

Yang L, Huang Y, Lima LV, Sun Z, Liu M, Wang J, Liu N, Ren H. 2021. Rethinking the ecosystem functions of *Dicranopteris*, a widespread genus of ferns. Front Plant Sci 11: 581513. DOI: 10.3389/fpls.2020.581513.

Yudaputra A. 2020. Modelling potential current distribution and future dispersal of an invasive species *Calliandra calothyrsus* in Bali Island, Indonesia. Biodiversitas 21 (2): 674-682. DOI: 10.13057/biodiv/d210233.

Zida D, Sanou L, Diawara S, Savadogo P, Thiombiano A. 2020. Herbaceous seeds dominates the soil seed bank after long-term prescribed fire, grazing and selective tree cutting in savanna-woodlands of West Africa. Acta Oecol 108: 103607. DOI: 10.1016/j.actao.2020.103607.