INVASIVE PLANT SPECIES IN THE DISTURBED FOREST OF BATUKAHU NATURE RESERVE, BALI, INDONESIA

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ABSTRACT

Patterns of invasive plant distribution and their underlying mechanisms are complex and vary with spatial scale. Within the mountainous tropical ecosystems of Bali Island, a local scale pattern of invasive plants is still poorly understood. This paper aimed to detect and investigate the presence of invasive species and to evaluate their relative abundance linked to forest site conditions along with an elevation range on Mount Pohen, Batukahu Nature Reserve, Bali, Indonesia. To identify the importance of environmental disturbances on species invasion, the disturbance-environmental factors and the species-environmental relationship were also measured and examined. Using the stratified random sample, 78 vegetation plots of 2 x 2 m size were established in four forest sites. Ten invasive plant species belonging to ten genera and five families were identified. Of these invasive species, 40% were herbs, while shrubs and grasses comprised 30%, respectively. *Austroeupatorium inulaefolium* has the highest frequency (45% of plots); followed by *Ageratina riparia* and *Brachiaria reptans* (40% of plots, respectively), *Melastoma malabathricum* (37%) and *Calliandra calothyrsus* (27%). *Austroeupatorium inulaefolium* was the most abundant invader, followed by *Ageratina riparia*, and the remaining invasive species were *Pennisetum purpureum, Calliandra calothyrsus, Imperata cylindrica, Brachiaria reptans, Melastoma malabathricum, Lantana camara, Bidens pilosa* and *Blumea lacera*, respectively. The distribution of invasive plants was strongly linked to the disturbance level of their respective habitat. The largest numbers invasive plants were present in burnt sites close to the forest edges with direct anthropogenic influence, while the undisturbed forest was the least invaded site. Further, the most invasive species mainly occurred at low elevations up to 1,600 m a.s.l. and were rarely found at higher elevations. However, few invasive species such as *Austroeupatorium inulaefolium* and *Melastoma malabathricum* were able to colonize the highest altitude (2,035 m a.s.l.), and to a lesser degree, *Ageratina riparia* and *Brachiaria reptans* were also distributed at high altitudes (1,950 m a.s.l. and 1,972 m a.s.l., respectively). This study provides a fine-scale analysis of invasive species distribution which will serve as a basis for conservation purposes, especially for strategic planning regarding the detection and management of invasive alien plants.

Keywords: distribution patterns, environmental gradients, invasive alien plants, mountainous regions, protected areas

INTRODUCTION

Biological invasions of alien species present a significant threat to biodiversity and ecosystems worldwide (Foxcroft *et al.* 2017; Early *et al.* 2016; Millennium Ecosystem Assessment 2005; Sala *et al.* 2000). The spread and establishment of non-indigenous species in their new locations have brought major impacts on the environment, economy and public health (Keller & Perring 2011; Vilà *et al.* 2011). Invasive species have high adaptability and ability to change and even disrupt the ecosystem functions of the newly colonized ecosystems. Invasions by alien plants alter ecosystem services and threaten the integrity as well as ecosystems functions (Walsh *et al.* 2016). In addition, the impacts of invading species are highlighted primarily due to the high potential of plant invaders to disturb bio-geographic conditions and environments. Future invasions have been predicted to increase rapidly under anthropogenic climatic changes (Diez *et al.* 2012; Bellard *et al.* 2013; Mooney & Hobbs 2000).

Batukahu Nature Reserve (also known as Bedugul Reserve) is an iconic natural

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mountainous ecosystem in Bali, Indonesia. Bedugul is highly important for human livelihood as it supports nature tourist attraction. However, the rapidly occurring forest fragmentation in the area has severe implications for the ecosystem and the biodiversity of this reserve; as the area, together with the 'naturalness' of the forest ecosystem was converted into settlement and agricultural landscapes. Its long history of anthropogenic disturbances makes this tropical nature reserve vulnerable to alien invasions. Previous studies focused on the biodiversity of Bedugul Reserve (e.g., Priyadi *et al.* 2014; Sutomo & Mukaromah 2010), however a local scale of patterns of invasive plants is still poorly understood. An assessment and monitoring of invasive plant species are important steps in detecting and managing non-native plants as well as protecting the indigenous forest resource and the whole range of forest biological integrity (Foxcroft *et al.* 2013). This study was conducted in a high-altitude tropical forest in Bedugul Reserve, Bali, to examine: 1) the distribution and abundance of invasive plant species linked to the different forest conditions at Mount Pohen, Batukahu Nature Reserve, Indonesia, 2) the ecological range of invasive species distribution along an elevation gradient, and 3) the environmental variables associated with the patterns of invasive plant species distribution. This study is the first to examine the presence and the abundance of invasive plants linked to forest site conditions along an elevation gradient at Mount Pohen.

MATERIALS AND METHODS

Study Area

Batukahu Nature Reserve (Bedugul Reserve) is located at the center of Bali Island, Bali Province, Indonesia (Fig. 1). It is located between 08°10'S-08°23'S and 115°02'E-115°15'E covering an area of 1,762.80 ha. This Nature Reserve comprises three mountain peaks (Mount Pohen, Mount Tapak, and Mount Lesung) and an endorheic basin with three volcanic lakes (Lake Beratan, Lake Buyan, and Lake Tamblingan). The area is mostly situated at altitudes higher than 1000 m with Mount Pohen reaching the highest at 2,069 meters above sea level (BKSDA Bali 2018). Mount Pohen is at the southeastern part of the Batukahu Nature Reserve that has a tropical wet climate with average annual precipitation of 236.69 mm, a relative air humidity ranging between 81.61% and 97.56%, and daily maximum and minimum temperatures at 24 °C and 11.54 °C, respectively.

Although Mount Pohen is a reserve, destructive human activities are prevalent in the area. In 1994, human-related wildfires destroyed its forest vegetation. Furthermore, the establishment of the Bedugul Geothermal Power within Mount Pohen was another form of human disturbance.

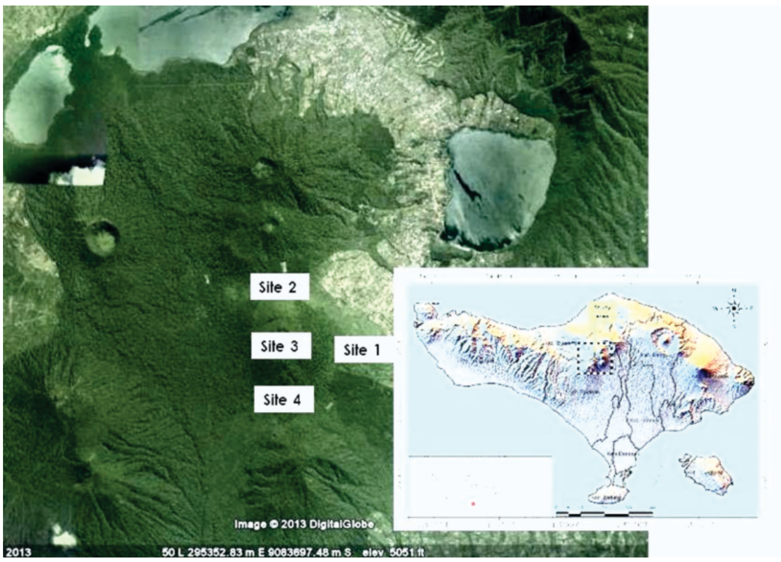

Figure 1 Map of the study area in Batukahu Nature Reserve of Bali Island, Indonesia (source: Google Earth)

Field Sampling

For sample collection, the forested area in the study sites was classified into four groups (i.e., undisturbed, lightly disturbed, moderately disturbed and highly disturbed) according to fire-affected areas and human impacts (Table 1). A total of 78 plots of 2 x 2 m size were established randomly at the four different strata. During the survey, different number of plots per stratum were chosen based on the presence of plants and the plot locations were recorded using Garmin GPSMAP 76Csx.

All the vascular plants present in each plot were recorded, and the non-native plants were identified as invasive (SEAMEO BIOTROP Database 2017). The coverage of each species was estimated visually using the Braun Blanquet cover-abundance scale (Mueller-Dombois & Ellenberg 1974). Samples of unknown plant species were photographed, collected and cross-checked at the herbaria of Purwodadi Botanical Garden. Data on topographical aspect and slope, elevation, air temperature and humidity at 1.5 m height, light intensity as well as the estimated percentage cover of the litter and bare ground were also collected to provide information on the environmental gradient of the study sites.

Data Analysis

The invasive species were classified into plant functional groups based on their life-forms (i.e., shrubs and herbs). The taxon name and the region of origin were also checked using the databases of Plant List Version 1.1 (www.theplantlist.org).

The frequency and abundance of each invasive species were calculated and a matrix of species abundance was developed to rank the abundances by total percent cover for each species across all plots and within each site. The elevation was examined as a function of the abundance of each invasive species data. The Non-Metric Multidimensional Scaling (NMDS) based on Sorensen distance was used for exploring the invaders–environment relationship using PC ORD software (McCune & Mefford 1999; McCune & Grace 2002). To examine the relationship between invasive plants and other ecological response variables, the species richness (S), Shannon–Wiener index (H'), and evenness (E), were also calculated for each sampled plot using the PC-ORD computer program (PC-ORD Version 4 for Windows, MjM Software design). The environmental variables and response variables were plotted on a diagram produced by NMDS. To evaluate their relationship with the patterns of invasive plants, the environmental gradients were investigated in each site by applying the join plot.

RESULTS AND DISCUSSION

Frequency Distribution of Invasive Plant Species

Ten invasive plant species belonging to ten genera and five families, were identified and recorded within the 78 study plots in the protected forest of Mount Pohen (Table 2). Family Asteraceae was the most dominant with four invasive species recorded, followed by Poaceae (three species), while Melastomaceae, Verbenaceae and Fabaceae contributed one species for each family. The invasive plants were dominated by perennials (7 species), while the remaining were annuals (3 species). Four species were herbs, whereas three species represented as shrubs and grasses, respectively. The majority of these invasive species originated from the American continent, while the other species came from Africa (one species) and Australia (one species) (Table 2).

Table 1 Site characteristics for the four forest sites along an altitudinal range on Mount Pohen

Site	Description	Number of plots	Elevation range (m a.s.l.)
undisturbed forest (site 1)	control sites (forest sites that were not affected by fire disturbance)	25	1,533-1,828
lightly disturbed forest (site 2)	forest sites less affected by wildfires	17	1,556-1,692
moderately disturbed forest (site 3)	forest sites severely affected by wildfires	15	1,542-2,035
highly disturbed forest (site 4)	forest sites severely affected by wildfires and human disturbance; located at the lower elevation corresponding to forest edges	21	1,461-1,548

Table 2 Geographic origin and life form of the invasive species

Scientific name	Family	Growth form*	Geographic origin/Nativity
Austroeupatorium inulaefolium (Kunth) R.M.King & H.Rob.	Asteraceae	Ph	South America, Central America
Ageratina riparia (Regel) R.M.King & H.Rob.	Asteraceae	Ph	Mexico, West Indies
Bidens pilosa L.	Asteraceae	Ah	Tropical America
Blumea lacera (Burm.f.) DC.	Asteraceae	Ah	Tropical America
Melastoma malabathricum L.	Melastomaceae	Ps	Tropical Asia, Polynesia, Australia
Lantana camara L.	Verbenaceae	Ps	Central America
Calliandra calothyrsus Meisn.	Fabaceae	Ps	Central America
Imperata cylindrica (L.) Raeusch.	Poaceae	Pg	Tropical America
Brachiaria reptans (L.) C.A.Gardner & C.E.Hubb.	Poaceae	Ag	Africa
Pennisetum purpureum Schumach.	Poaceae	Ag	Tropical America

Note: *Growth form: Ah=annual herb; Ph=perennial herb; Ps=perennial shrub; Ag=annual grass; Pg=perennial grass.

The invasive plants infested 91% of the 78 plots in the nature reserve of Mount Pohen. However, these invasive species did not occupy seven sites at the undisturbed sites. This indicated that a higher degree of human disturbance resulted in a higher number of plots containing invasive plants. The proportion of plots that contained invasive plants varied between sites; being highest in the highly disturbed site and lowest in the undisturbed site (Table 3).

The most frequently occurring species was *Austroeupatorium inulaefolium* (45% of plots), followed by *Ageratina riparia* and *B. reptans* (40% of plots), *Melastoma malabathricum* (37%) and *Calliandra calothyrsus* (27%) (Table 3). These five invasive plants occurred in all four different sites Pohen Natural Reserve, including the undisturbed sites. Each species frequently occurred at the most disturbed sites yet, two invasive plants (*Melastoma malabathricum* and *Brachiaria reptans*) had the highest frequency at the undisturbed site.

Expansion Range of Invasive Species along an Elevation Gradient

Several invasive species were found along with a broad elevation range; from the lowest elevation site up to the highest peak of Mount Pohen (Fig. 2). *Austroeupatorium inulaefolium* was widely distributed up to the highest peak of Mount Pohen (2,035 m a.s.l.) and *Ageratina riparia* also had extensive altitudinal amplitude and reached an elevation of around 1,950 m a.s.l. *Melastoma malabathricum* and *Brachiaria reptans* were also broadly distributed at different elevations. Particularly, *Melastoma malabathricum* reached the highest elevation. *Blumea lacera*, from the Asteraceae family, also occurred at a high elevation of 1,972 m a.s.l., but only at four plots. Other invasive plants (i.e., *Calliandra calothyrsus, Lantana camara, Pennisetum purpureum* and *Bidens pilosa*) commonly occurred at lower elevations, but not higher than 1,600 m a.s.l. Similarly, *Imperata cylindrica* was frequently distributed along the forest border and became rare above 1,650 m a.s.l.

Table 3 Frequency distribution of invasive plant species at Mount Pohen

Invasive plants	Number of plots with species present (frequency per sites)				Maximum relative frequency	Total frequency (%)
	site 1	site 2	site 3	site 4		
Austroeupatorium inulaefolium	1	6	11	17	17	44.87
Ageratina riparia	5	6	4	16	16	39.74
Brachiaria reptans	12	9	4	6	12	39.74
Melastoma malabathricum	10	3	8	8	10	37.18
Calliandra calothyrsus	1	2	2	20	20	26.92
Pennisetum purpureum	0	0	0	15	15	19.23
Imperata cylindrica	0	6	1	8	8	19.23
Lantana camara	0	3	0	3	8	7.69
Blumea lacera	2	0	1	1	2	5.13
Bidens pilosa	0	0	0	1	1	1.28

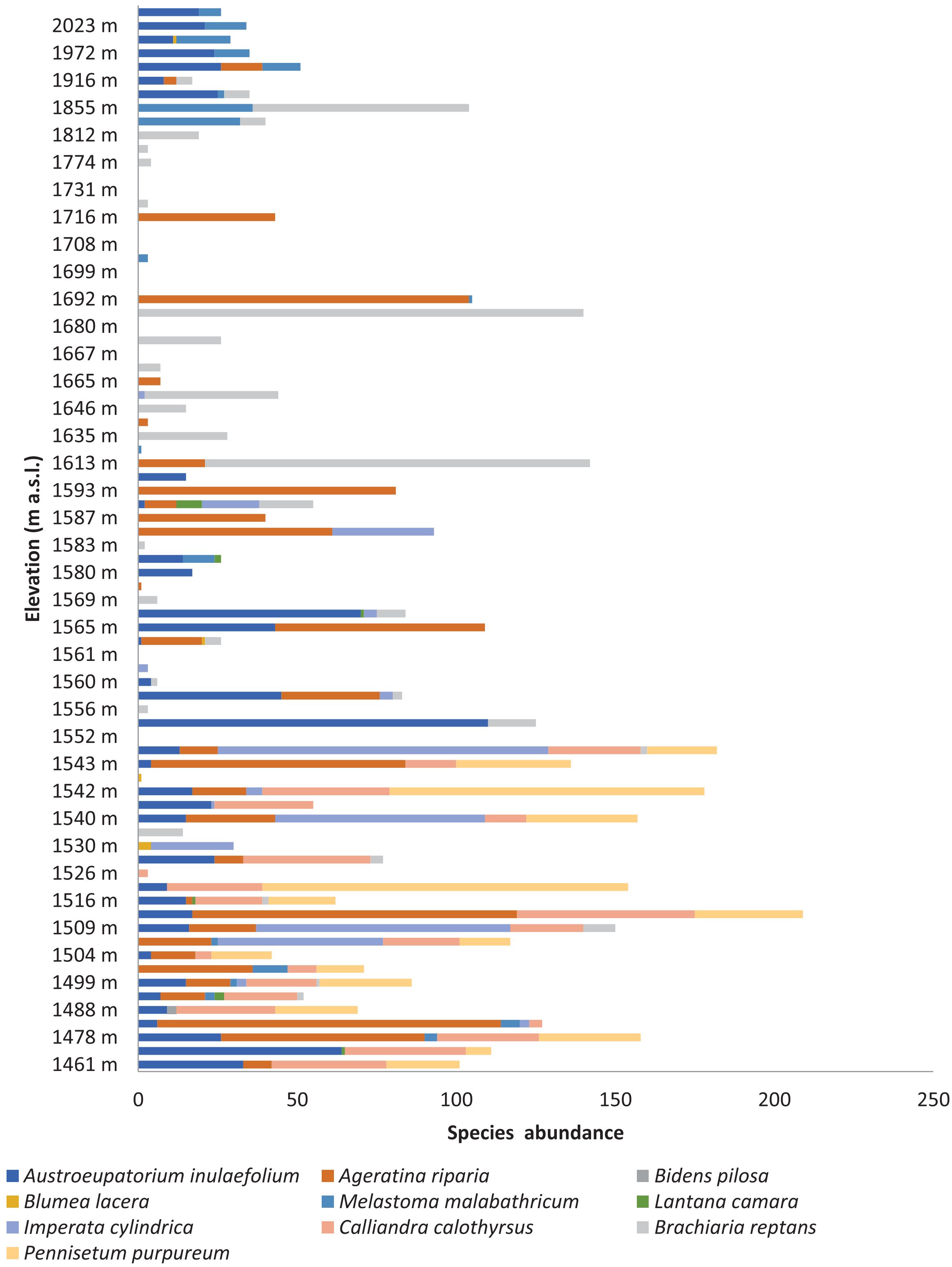

Figure 2 Altitudinal amplitude (1,461-2,023 m a.s.l.) and the abundance of the invasive species

Abundance of Invasive Plants Linked to Habitat Condition

The abundance of each individual varied between sites (Fig. 3). The abundance of *Austroeupatorium inulaefolium* was highly variable; being the most dominant over the others at site 3, but less abundant at site 1. *Ageratina riparia* had an exceptional abundance clearly noticeable at site 4 while more abundant at site 2 than at site 3. Other invasive species (i.e., *Calliandra calothyrsus* and *Imperata cylindrica*) also occurred abundantly, yet particularly invaded the most disturbed sites at the lower altitudes associated with the forest edges (site 4). In the undisturbed sites, different patterns were observed where *Brachiaria reptans* was the most abundant followed by *Melastoma malabathricum* and *Ageratina riparia*.

Generally, a high number of invasive plants were observed in the fire-affected sites (site 3 and 4) than those of the undisturbed sites (site 1) and lightly disturbed sites (site 2), indicating that disturbed habitats were more favorable sites for invasive plant species. In terms of total abundance, *Austroeupatorium inulaefolium* was the most abundant followed by *Ageratina riparia* (2nd) *Brachiaria reptans* (3rd), *Calliandra calothyrsus* (4th), *Imperata cylindrica* (5th), *Pennisetum purpureum* (6th), and *Melastoma malabathricum* (7th). *Lantana camara* (8th) was less abundant and less widespread, while *Blumea lacera* (9th) and *Bidens pilosa* (10th) were rarely observed in the study area (Fig. 3).

Relationship between Invasive Plants and Environmental Factors

Based on ordination analysis, several invasive plants were aggregated closely with a high score on both axes 1 and 3 (final stress of 0.23 with successive axes explaining 25.6% and 23.4% of the variation in the rank distance matrix, respectively, for a total r^2 of 74.3%) (Fig. 4). *Ageratina riparia*, *Austroeupatorium inulaefolium*, *Calliandra calothyrsus*, *Imperata cylindrica*, and *Pennisetum purpureum* were strongly associated with light intensity and temperature. Most invaders had maximum abundance at highly disturbed sites or the forest edges (site 4). *Lantana camara*, which was less frequent and less abundant, was also associated with a high score at axis 1. This first NMDS axis correlated positively with evenness and Shannon-Wiener diversity indices. A different pattern was observed for *Melastoma malabathricum*. The species was associated with a low score at axis 1, corresponding to topographic factors of elevation, topographical aspect and slope. *Blumea lacera* had similar patterns with *Brachiaria reptans* with a low value at axis 3. *Bidens pilosa* was only observed in one plot, likely occurring as an outlier with high value at axis 3.

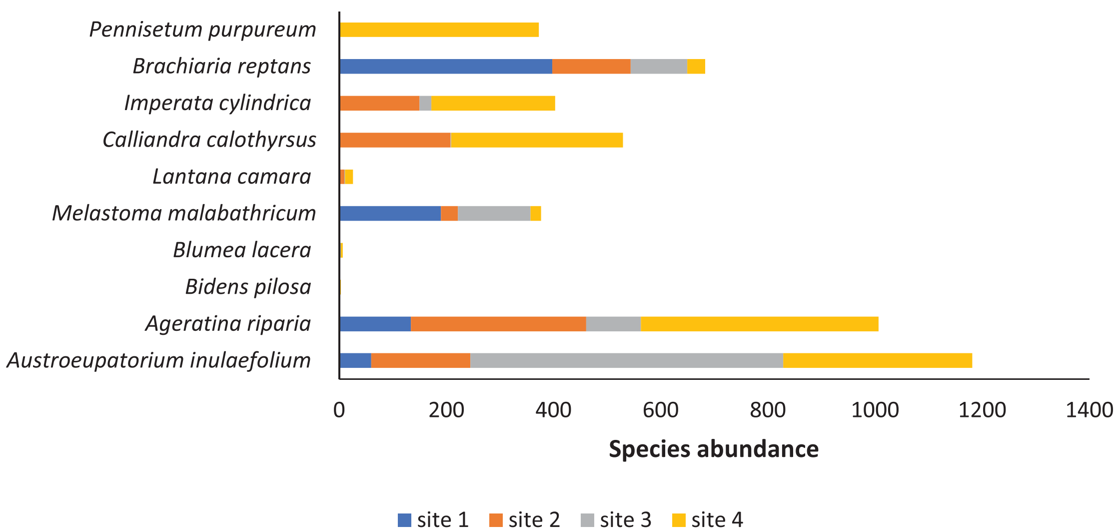

Figure 3 The abundance of invasive species at each site and their total abundance for all sites
Notes: Site 1: undisturbed, Site 2: lighty disturbed, Site 3: moderately disturbed, Site 4: highly disturbed.

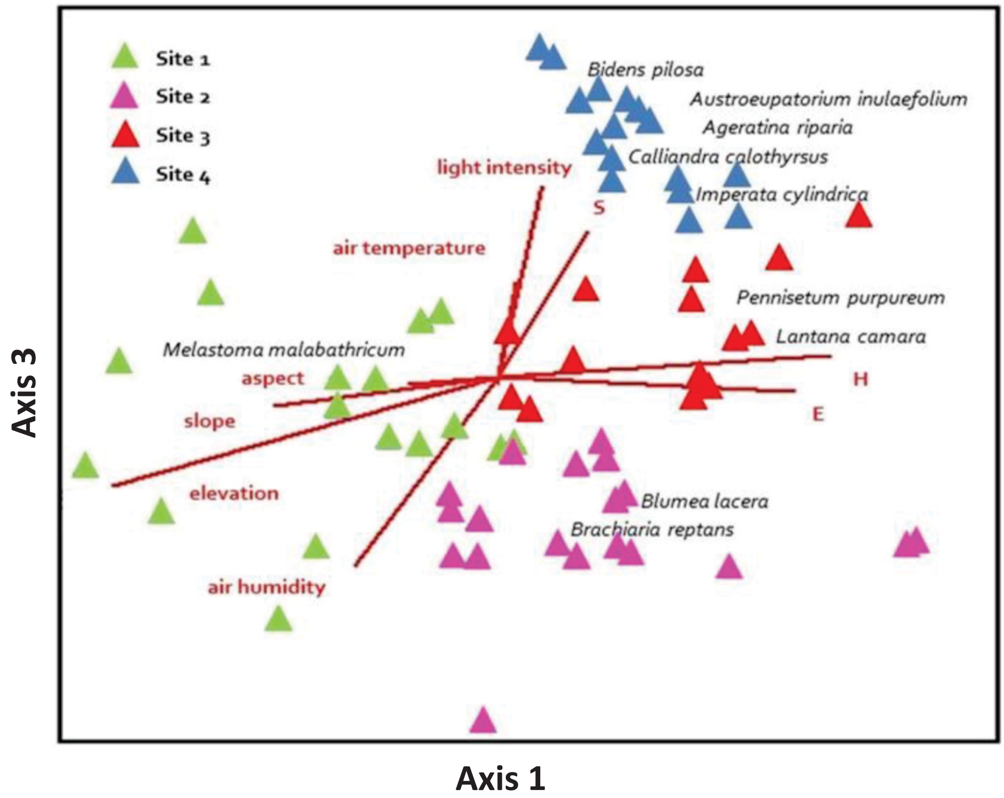

Figure 4 Ordination diagram showing NMDS floristic dissimilarity inside the 78 plots based on Sorensen distance with environmental variable vectors (Monte Carlo test $p < 0.001$)

Most invasive species had largely occupied the fire-affected sites (sites 3 and 4) and were less found than those of the undisturbed and less disturbed sites, indicating higher invasibility of those burnt forest sites. Environmental disturbances, such as forest fire often leads to a decrease of native assemblage and creates niche opportunities for invaders (Bugnot *et al.* 2016). Canopy disturbance was clearly observed in the fire-affected sites of the reserve, where herbs and shrubs were expectedly very dominant (Mukaromah 2015). Although the undisturbed sites are somehow resistant to invasion, the presence of the invasive species in the study area indicated their potential to invade undisturbed forests. Out of 25 plots of the undisturbed site, only seven sites were not occupied by the invasive plants. Six invasive species were found in the undisturbed sites, of which *Melastoma malabathricum* was the most abundant. This invader frequently occurred in the different site conditions along the entire elevation range, yet its spread is apparently associated with the undisturbed sites. *Brachiaria reptans* was also frequent and abundant at the undisturbed sites. During the field survey, *M. malabathricum* and *B. reptans* were also frequently observed along the walking trails. *Melastoma malabathricum* was notably the dominant understory in the undisturbed forest, suggesting its being a shade-tolerant species. *M. malabathricum* is a fast-growing adaptable shrub that is often reported as a pioneer species that colonizes disturbed sites (Manjul & Metali 2016; Sunaryo 2015).

The frequency, abundance, and elevation range of the 10 invasive species showed that *Austroeupatorium inulaefolium* and *Ageratina riparia* were the most abundant and widespread invaders. Both species belong to the Asteraceae family and have highly viable seeds, providing a great potential for long-distance dispersal across the mountain (Datta *et al.* 2017; Hao *et al.* 2010; Noyes 2007). *A. inulaefolium* was reported as invasive species in other protected areas in Indonesia, such as Mount Merbabu (Padmanaba *et al.* 2017), Mount Gede Pangrango National Park (Zuhri & Mutaqien 2013; Kudo *et al.* 2014), and Halimun-Salak National Park (Zuhri & Mutaqien 2013; Kudo *et al.* 2014), while *A. riparia* was also found in mountainous park in Java, such as Halimun-Salak National Park (Kudo *et al.* 2014), Gede Pangrango National

Park (Padmanaba *et al.* 2017), Bromo Tengger Semeru National Park (Padmanaba *et. al.* 2017; Zulharman 2017), and Mount Merapi - Mount Merbabu (Padmanaba *et al.* 2017). As the most mountainous areas in Java commonly have human access up to the mountain top, the forest tracks served as corridors that facilitated the dispersal and provide subsequent paths for invasive species to spread and expand into higher elevations. The spread of *Austroeupatorium inulaefolium* and *Ageratina riparia* likely responded in a similar way to the disturbed sites along elevation gradients. The abundance values revealed that these species did not only highly invade the most disturbed sites at the lower elevation, but these also had the widest ecological ranges, spreading into the highest elevation. This suggested that forest disturbances related to fire may increase the susceptibility of forests to invasion, while anthropogenic disturbances may open opportunities for invasive plants to spread into the higher elevation of mountainous regions (Lembrechts *et al.* 2016; Menuz & Kettenring 2013). Disturbed sites associated with anthropogenic disturbances could assist in the spread of invasive plants into higher elevation sites (Mukaromah 2016; McDougall *et al.* 2011; Pyšek *et al.* 2011).

The most common alien species occurring at Mount Pohen are also among the most detrimental invasive species worldwide. *Calliandra calothyrsus* is also common in protected areas in Java, such as Mt. Gede Pangrango and Halimun-Salak National Park, West Java (Zuhri & Mutaqien 2013; Kudo *et al.* 2014; Sunaryo *et al.* 2012). This perennial shrub is one of the most successful invasive shrubs which thrives under a wide range of climatic conditions (Invasive Species Compendium 2017b). *Imperata cylindrica* is also considered as one of the worst weeds that has the ability to colonize new areas, grow rapidly and form dense thickets (Global Invasive Species Database 2017b). This grass species is also an invasive species in Bromo Tengger Semeru (Zulharman 2017) and Tanjung Puting National Park (Sunaryo 2015). *Pennisetum purpureum* is another fast-growing perennial grass that has a great ability to alter ecosystem functions by altering fire regimes, community composition, biophysical dynamics, and cycles of hydrology and nutrients (D'Antonio & Vitousek 1992). This widely naturalized species also exhibited a potential allelopathic effect (Tan *et al.* 2012). Since this grass species is invasive, the use of this species therefore, should be done outside of protected areas. Another invasive species in the highly disturbed site, *Lantana camara*, was less abundant and especially less widespread as compared to the other invasive plant species. *Lantana camara* typically invades forest borders, but is not found in the intact rain forests (Balaguru *et al.* 2016). Introduced as an ornamental plant into Europe from Brazil in the 17th century and at Calcutta Botanical Garden (Srilanka) in 1809, this woody shrub is now a well acknowledged alien invader which posed threat to native plant communities under various habitats throughout the tropical, subtropical and warm temperate areas (GISIN 2013; Taylor & Kumar 2013). *L. camara* is listed as one of the 100 "World's Worst" invaders possessing great ability to thrive in almost any environment (Global Invasive Species Database 2017a; Invasive Species Compendium 2017a).

This study confirmed the importance of human-impact factors and environmental filtering in driving alien plants in mountainous regions (Alexander *et al.* 2011). There were higher numbers of invasive plants on more degraded, fire-affected, and human-induced disturbance (site 4) than those of the sites only affected by fire (site 3), signifying that fire-affected sites located at a lower elevation were even more highly vulnerable to invasive species. The lower elevation site associated with forest borders likely had comparatively favorable growing conditions due to greater frequency of human disturbance. Invasive plant species were most prominent at site 4 (with the highest disturbance level), including *Austroeupatorium inulaefolium*, *Ageratina riparia*, *Calliandra calothyrsus, Imperata cylindrica*, *Lantana camara* and *Pennisetum purpureum*. While *A. inulaefolium* and *A. riparia* had wide distribution and reached the highest elevation sites, other highly abundant species showed a tendency to colonize the disturbed sites along the forest borders located at lower elevations (i.e., *C. calothyrsus, I. cylindrica* and *P. purpureum*), and to a lesser degree *L. camara* that was mostly absent from the undisturbed forest and high elevation sites. This study results reflect differing environmental conditions at the lower elevation site associated with forest borders which act as microhabitats for many invasive plant species and facilitated their spread into less disturbed environments of the forest interior. Similar patterns were observed by other studies that highly disturbed sites associated with forest edges are likely more vulnerable to invasion (Bugnot *et al.* 2016; Dawson *et al.* 2015; Pollnac *et al.* 2012). The forest edges encompass a complex biotic and abiotic connection across forest borders and may serve as propitious habitats for the establishment of alien plant species (Dawson *et al.* 2015; Pollnac *et al.* 2012). Moreover, the edge effect is one most significant driver of ecological change in fragmented forest habitats (Dillon *et al.* 2018). Edge effects can even shift the species composition towards pioneer species (Lippock *et al.* 2014). While synergies between fire and anthropogenic disturbances create severe consequences on forest ecosystems and strongly influence plant invasions, the differing environmental factors (microclimate and microtopography) also appear to drive the invasion success of alien species on the mountain ecosystems.

Implication for Conservation

This study provides the first fine-scale assessment of invasive species in Mount Pohen, Batukahu Nature Reserve, Bali. It also offers knowledge on the current status of invasive plant species to policy makers to develop an effective program and proper actions in controlling and monitoring the invasive plants in this mountainous ecosystem. Furthermore, these fine-scale data on the present distribution and abundance of invasive plant species are important to determine future quantitative vegetation changes in Mount Pohen which are exposed to various factors of environmental conditions and human activities.

CONCLUSION

The presence and abundance of invasive plants differ along disturbance gradients, with the highest invasion at the most disturbed sites and the lowest at the undisturbed sites, highlighting the negative impact of fire disturbance and anthropogenic pressure on the nature reserve of this mountain ecosystem. Among the ten recorded invasive plants, *Ageratina riparia* and *Austroeupatorium inulaefolium* were the most abundant and widespread; suggesting a very high invasive potential. Few invaders have also spread to such magnitude that they are present in all forest sites along an elevation gradient, and likely indicate that they may well become much more widespread and influential in the future, especially due to anthropogenic changes.

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