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

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Running title: Invasive plant species in Batukahu Nature Reserve

ABSTRACT

Patterns of invasive plants distribution and their underlying mechanisms are complex and may vary with spatial scale. Within the mountainous tropical ecosystems of Bali Island, a local scale of patterns 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 condition along an elevation ranges 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. A total of 78 vegetation plots of 2x2 m size were established in four forest sites using the stratified random sample. Ten invasive plant species belonging to ten genera and five families in the study area were identified. Of these invasive species, 40% were herbs, while shrubs and grasses comprised 30% respectively. Austroeupatorium inulaefolium occurred at 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, in order, Pennisetum purpureum, Calliandra calothyrsus, Imperata cylindrica, Brachiaria reptans, Melastoma malabathricum, Lantana camara, Bidens pilosa, and Blumea lacera. The results demonstrated that the distribution of invasive plants was strongly linked to the disturbance level of the according habitat. The largest numbers of 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 results demonstrated that most invasive species were mainly occurred at low elevations up to 1600 m a.s.l. and were rarely found in higher elevations. However, few invasive species such as Austroeupatorium inulaefolium and Melastoma malabathricum were also able to colonize the highest altitude (2035 m a.s.l.), and to a lesser degree, Ageratina riparia and Brachiaria reptans were also distributed into high altitude areas (1950 m a.s.l. and 1972 m a.s.l. respectively). This study provides a fine-scale analysis of invasive species distribution in this protected area which can be used as a reliable 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 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; Denslow et al. 2011). The spread and establishment of nonindigenous species in their new
environments have emerged major impacts on the environment, economy, and public health (McNeely et al. 2001; Pimentel et al. 2001; Vilà et al. 2011; Wu et al. 2011). Invasive species have high adaptability and ability to change and even disrupt the ecosystem functions. Studies have reported that invasions by alien plants alter ecosystem services and threaten the integrity as well as ecosystems functions (Mack et al. 2000; Ricciardi et al. 2005; Mooney et al. 2005). In addition, the impacts of invading species are highlighted primarily due to the high potential plant invaders to disturb bio-geographic conditions and environments. Future invasions have been predicted to increase rapidly under anthropogenic climate change (Diez et al. 2000; Bellard et al. 2005; Mooney & Hobbs 2000).

Batukahu Nature Reserve (also known as Bedugul Reserve) is an iconic natural mountainous ecosystem in Bali, Indonesia. Bedugul is of great importance for human livelihood benefits in many ways that also support nature tourist attraction. However, rapidly occurring forest fragmentation in this area has severe implications for the ecosystem and the biodiversity of this reserve, as the area and ‘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 have documented forest 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 in detecting and managing non-native plants as well as protecting forest resource and 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 different forest conditions at Mount Pohen, Batukahu Nature Reserve, Bali, 2). the ecological range of invasive species distribution along an elevation gradient, 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 condition along an elevation gradient at the Mount Pohen.

MATERIALS AND METHODS

Study Area

Batukahu Nature Reserve (Bedugul Reserve) is located in the centre of Bali Island, Bali Province, Indonesia (Figure 1). It is located between 08°10′-08°23′ S and 115°02′-115°15′ E, and covers an area of 1.762,80 ha. This Nature Reserve comprised of mountain areas (Mount Pohen, Mount Tapak, and Mount Lesung) and an endorheic basin with three volcanic lakes (Lake Beratan, Lake Buyan, and Lake Tamblingan). Most area is higher than 1000 m in altitude, and the highest peak is Mount Pohen that reaches 2069 meter above sea level (BKSDA Bali 2018). We surveyed
the Mount Pohen, the southeastern part of Batukahu Nature Reserve. The area has a tropical wet climate with average annual precipitation of 236.69 mm, and the relative air humidity ranges between 81.61% and 97.56%. The daily maximum and minimum temperature are 24°C and 11.54°C, respectively.

Although the Mount Pohen is a reserve, the human effect is also occurring in reserve. In 1994, wildfires destroyed the forest vegetation on the Mount Pohen. Furthermore, the establishment of the Bedugul Geothermal Power within the nature reserve area of Mount Pohen is also represented human disturbance.

Field Sampling

The forest area in the study sites was stratified into four groups, (i.e. undisturbed, lightly disturbed, moderate disturbed, and highly disturbed), according to fire-affected area and human impacts for sample collection (Table 1). A total of 78 plots of 2x2 m size were placed randomly in the four different strata. A different number of plots for each stratum was collected based on their presence during the survey and recorded the location of each plots using Garmin GPSMAP 76Cx.

All of the vascular plant species present in each plot were recorded, and the non-native plants were identified as invasive (checked with Invasive Species Compendium, Global Invasive
Species Database, Invasive Alien Species Database of SEAMEO BIOTROP). The coverage of each species was estimated visually using Braun Blanquet cover-abundance scale (Mueller-Dombois and Ellenberg 1974). Samples of unknown plant species were photographed, collected, and checked in herbaria of Purwodadi Botanic Garden. Data on topographical aspect and slope, elevation, air temperature and humidity (at 1.5 m height), light intensity, and estimated percentage cover of 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). Taxon name and the region of origin were also checked using the databases of Plant List Version 1.1 (www.theplantlist.org).

Frequency and abundance of each invasive species were calculated and a matrix of species abundance was developed to rank abundances by total percent cover for each species across all plots and within each site. The elevation was examined as a function of abundance of each invasive species data. Non-Metric Multidimensional Scaling (NMDS based on Sorensen distance) was used for exploring the invaders – environment relationship using PC ORD software (McCune and Mefford 1999; McCune and Grace 2002). To examine the relationship between invasive plants and other ecological response variables, 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). 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.

<table>
<thead>
<tr>
<th>Site Description</th>
<th>Number of plots</th>
<th>Elevation range (m a.s.l.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>undisturbed forest (site 1)</td>
<td>control sites (forest sites that were not affected by fire disturbance)</td>
<td>25</td>
</tr>
<tr>
<td>lightly disturbed forest (site 2)</td>
<td>forest sites less affected by wildfire</td>
<td>17</td>
</tr>
<tr>
<td>moderately disturbed forest (site 3)</td>
<td>forest sites severely affected by wildfires</td>
<td>15</td>
</tr>
<tr>
<td>highly disturbed forest (site 4)</td>
<td>forest sites severely affected by wildfires and human disturbance; located at the lower elevation correspond to forest edges</td>
<td>21</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

Frequency distribution of invasive plant species

A total of 10 invasive plant species were recorded and identified within the 78 study plots in the protected forest of Mount Pohen (Table 2). These species belong to ten genera and five families. Asteraceae was the most dominant family with four invasive species recorded, followed by Poaceae (three species), while other families (i.e., Melastomaceae, Verbenaceae, and Fabaceae) comprised only one species respectively. The invasive plants were dominated by perennials (7 species), while the remaining were annuals (3 species). Herbs constituted four species, whereas three species represented as shrub and grasses respectively. American continents contributed to the majority of the origin of invasive species in the present study, while other regions (i.e., Africa and Australia) contributed only one species each (Table 2).

Table 2. Geographic origin and life form of recorded invasive species

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

Note: Growth form: Ah, annual herb; Ph, perennial herb; Ps, perennial shrub; Ag, annual grass; Pg, perennial grass

The results demonstrated that invasive plants infested 91% of 78 plots in the nature reserve of Mount Pohen. Invasive species did not occupy seven sites which belong to the undisturbed sites. It seems that the higher human disturbance contributed to a higher number of plots that contained 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 frequent species in this study was *Austroeupatorium inulaefolium* (45% of plots), followed by *Ageratina riparia* and *B. reptans* (40% of plots, respectively), *Melastoma malabathricum* (37%), and *Calliandra calothyrsus* (27%) (Table 3). These five invasive plants occurred in all four different sites of the Pohen Natural Reserve, including the undisturbed sites. Each species was frequently demonstrated at the most disturbed sites; yet, two invasive plants (i.e., *Melastoma malabathricum* and *Brachiaria reptans*) showed the highest frequency at the undisturbed site.

Table 3 The frequency of invasive plant species in Mount Pohen Nature Reserve

<table>
<thead>
<tr>
<th>Invasive plants</th>
<th>Number of plots with species present (frequency per sites)</th>
<th>Maximum relative frequency</th>
<th>Total frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>site 1</td>
<td>site 2</td>
<td>site 3</td>
</tr>
<tr>
<td><em>Austroeupatorium inulaefolium</em></td>
<td>1</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td><em>Ageratina riparia</em></td>
<td>5</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td><em>Brachiaria reptans</em></td>
<td>12</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td><em>Melastoma malabathricum</em></td>
<td>10</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td><em>Calliandra calothyrsus</em></td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><em>Pennisetum purpureum</em></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><em>Imperata cylindrica</em></td>
<td>0</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td><em>Lantana camara</em></td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td><em>Blumea lacera</em></td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><em>Bidens pilosa</em></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Expansion range of invasive species along an elevation gradient

Several invasive species had a broad elevation range from the lowest elevation site up to the highest peak of Mount Pohen (Figure 2). *Austroeupatorium inulaefolium* was observed in wide distribution reaching the highest peak of Mount Pohen (2035 m a.s.l.), and *Ageratina riparia* also had extensive altitudinal amplitude and reached the elevation up to around 1950 m a.s.l. *Melastoma malabathricum* and *Brachiaria reptans* were also broadly distributed at different elevations. Especially for *Melastoma malabathricum*, it reached the highest elevation. *Blumea lacera*, an invasive plant from the family of Asteraceae, also occurred at high elevation at 1972 m a.s.l., yet this invasive only occurred at four plots. Other invasive plants (i.e., *Calliandra calothyrsus*, *Lantana camara*, *Pennisetum purpureum*, and *Bidens pilosa*) were common at lower elevation sites and reached no higher than 1600 m a.s.l. Similarly, *Imperata cylindrica* was frequently distributed along the forest border and became rare above 1650 m a.s.l.
Figure 2 The altitudinal amplitude (1461 – 2023 m asl) and the abundance of each invasive plant species calculated for each plot as a function of elevation at any forest site conditions.

Abundance of invasive plants linked to habitat condition

The abundance of each individual varied between sites (Figure 3). The abundance of *Austroeupatorium inulaefolium* was highly variable; being the most dominant at site 3 over the...
others but less abundant at site 1. For *Ageratina riparia*, variations in abundance were also recorded among sites, with an exceptional abundance clearly noticed at site 4. While *Ageratina riparia* was more abundant at site 2 than at site 3. Other invasive (i.e., *Calliandra calothyrsus* and *Imperata cylindrica*) also occurred abundantly, yet they particularly invaded the most disturbed sites at the lower altitude sites correlated with the forest edges (site 4). In the undisturbed sites, different patterns were observed where *Brachiaaria reptans* was the most abundant followed by *Melastoma malabathricum* and *Ageratina riparia*.

In general, 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 for invasive plant species. In term of total abundance for each individual recorded in all sites, *Austroeupatorium inulaefolium* was the most abundant invasive plant, followed by *Ageratina riparia* (Figure 3). *Calliandra calothyrsus* and *Imperata cylindrica* ranked fourth and fifth highest after *Brachiaaria reptans*, followed by *Pennisetum purpureum* and *Melastoma malabathricum*. *Lantana camara* was less abundant and less widespread, while *Blumea lacera* and *Bidens pilosa* were rarely observed in the study area.

![Graph showing species abundance across sites](image)

**Figure 3** The abundance of invasive species at each site and the total abundance of each invaders observed for all sites. Site 1: undisturbed, Site: 2 lightly disturbed, Site: 3 moderately disturbed, Site 4: highly disturbed.

**Relationship between invasive plants and environmental factors**

Ordination analysis shown in Figure 4 revealed that 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 r² of 74.3%). These species including *Ageratina riparia*, *Austroeupatorium inulaefolium*, *Calliandra*
Callothysurus, Imperata cylindrica, and Pennisetum purpureum were strongly associated with light intensity and temperature. As expected, most invaders had abundance maxima at highly disturbed sites correspond to the forest edges (site 4). Lantana camara, which was less frequent and less abundant, was also associated with a high score of axis 1. This first NMDS axis correlated positively with evenness and Shannon Wiener diversity. Different patterns observed for Melastoma malabathricum. This species was associated with a low score of axis 1, and topographic factors (i.e. elevation, topographical aspect and slope) explained these patterns. Blumea lacera had similar patterns with Brachiaria reptans along the low value of axis 3. Bidens pilosa observed only in one plot likely occurred as an outlier on the high value of axis 3.

![Ordination diagram showing NMDS floristic dissimilarity in 78 plots based on Sorensen distance with environmental variable vectors (Monte Carlo test p<0.001)](image)

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

Our results showed that most invasive species had invaded large parts of the fire-affected sites (sites 3 and 4) than those of the undisturbed and less disturbed sites, indicating higher invasibility of those burnt forest sites. Disturbance of the environment such as forest fire often leads to a decrease of native assemblage and creates niche opportunities for invaders (Fisher et al. 2009). Canopy disturbance was clearly observed in the burned areas of this nature reserve, whereas herbs and shrubs were very dominant at these fire-affected sites (Mukaromah 2015). While the undisturbed sites are expected somehow resistant to plant invasion, our results however indicated
that the presence of invasive species was potentially able to invade the undisturbed forest. Out of 25 plots of the undisturbed site in this study, only seven sites were not invaded by invasive plant species. Six invasive species were found in the undisturbed sites, of which *Melastoma malabathricum* had highest abundance in this site. This invader was frequented in all different site conditions and occurred along the entire elevation range, yet its spread appeared to be related to the undisturbed sites. *Brachiaria reptans* was also frequent and abundant especially at the undisturbed sites. During the field survey, *M. malabathricum* and *Brachiaria reptans* were also frequently observed along the walking trails. It is important to note that *Melastoma malabathricum* becomes the dominant understory in the undisturbed forest, suggesting the ability to be shade-tolerant. *Melastoma malabathricum* is a fast-growing and adaptable shrub that is often reported as pioneer species that colonizes disturbed sites (Gross 1993; SEAMEO BIOTROP 2017; Sunaryo 2015).

The results on 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 family of Asteraceae 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). *Austroeupatorium inulaefolium* was also reported as invasive species in other protected areas in Indonesia, such as Alas Purwo National Park (Hakim *et al.* 2005), Mount Merbabu (Padmanaba *et al.* 2017) and Mount Gede Pangrango National Park (Zuhri & Mutaqien 2013; Kudo *et al.* 2014) and Halimun-Salak National Park (Zuhri & Mutaqien, 2013; Kudo *et al.* 2014). *Ageratina riparia* was also found in mountainous park in Java, such as Halimun-Salak National Park (Kudo *et al.* 2014) and Bromo Tengger Semeru National Park (Padmanaba *et al.* 2017; Zulharman 2017). Padmanaba *et al.* (2017) also reported the spread of *Ageratina riparia* on Mount Merbabu, Mount Merapi, and Gede Pangrango National Park. As most mountainous areas in Java commonly have human access into the top of the mountain, forest tracks may provide corridors that facilitate dispersal and subsequent paths for invasive species to spread and expand into higher elevations. The results indicated that the spreads of *Austroeupatorium inulaefolium* and *Ageratina riparia* likely respond in a similar way to the disturbed sites along elevation gradients. Their abundance revealed that they were not only highly invade the most disturbed sites at a lower elevation, but they also had the widest ecological ranges spreading into the highest elevation. This suggests that forest disturbances related to fire may increase the susceptibility of forests to invasion, while anthropogenic disturbance may open opportunities for invasive plants to spread into high elevation of mountain regions (Lembrechts *et al.* 2016; Mortensen *et al.* 2009). Similar findings have also reported that disturbed sites associated with anthropogenic disturbance could assist in the spread of invasive plants into higher elevation sites (Pauchard *et al.* 2009; Mukaromah 2016; McDougall *et al.* 2011; Pyšek *et al.* 2011).
The most common alien species occurring in the Mt 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 has been reported as one of the most successful invasive shrubs in the world which thrives under a wide range of climatic conditions (Invasive Species Compendium 2017). *Imperata cylindrica* is also considered to be one of the worst weeds in the world that has the ability to grow rapidly, colonize new areas, and form dense thickets (Global Invasive Species Database 2017). This grass species is reported as invasive species in Bromo Tengger Semeru (Zulharman 2017) and Tanjung Puting National Park (Sunaryo 2015). Other grass species, *Pennisetum purpureum*, is 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 and Vitousek 1992). Tan et al. (2012) reported that this widely naturalized species has a potential allelopathic effect. Since this grass species is invasive, the use of this species therefore should be done outside of protected areas. Other invasive species of the highly disturbed site in this study, *Lantana camara*, was less abundant and especially less widespread as compared to the invasive plant species stated above. Balaguru et al. (2016) reported that *Lantana camara* typically invades forest borders but is not found in the intact rain forests. 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 well acknowledged alien invaders which posed threat to native plant communities under various habitats throughout tropical, subtropical and warm temperate areas (GISIN 2013; Lowe et al. 2000; Sharma et al. 1988; Swarbrick et al. 1995). *Lantana camara* is listed as one of the 100 “World's Worst” invaders that has great ability to thrive in almost any environment (Global Invasive Species Database 2017; Invasive Species Compendium 2017).

The study confirmed the importance of human-impact factors and environmental filtering in driving alien plants in mountain 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 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 related to forest borders likely had comparatively favorable growing conditions due to greater frequency of human disturbance. Indeed, 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 *Austroeupatorium inulaefolium* and *Ageratina 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. Calliandra calothyrsus, Imperata cylindrica, and Pennisetum purpureum), and to lesser degree Lantana camara that mostly absent from the undisturbed forest and high elevation sites. The findings of this study might reflect differing environmental conditions at the lower elevation site related to forest borders which act as microhabitats for many invasive plant species and facilitate their spread into less disturbed environments of the forest interior. We detected similar patterns with other studies that highly disturbed sites associated with forest edges are likely more vulnerable to invasion (Honnay et al. 2002; 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; Pauchard & Alaback 2006; Pollnac et al. 2012). In addition, edge effects are acknowledged as one of most significant drivers of ecological change in fragments of forest habitats (Laurance et al. 2007; Murcia 1995), and Lippock et al. (2014) also reported the edge effects on shifting the species composition towards pioneer species. While synergies between fire and anthropogenic disturbance likely have severe consequences on forest ecosystems and have strong influence on plant invasion, differing environmental factors (i.e. microclimate and microtopography) also appear to thrive the invasion success of alien species on 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 of the current state of invasive plant species in this nature reserve to policymakers and allows them to develop an effective program to deal with invasive plants and to take a proper action to control and monitor invasive plants in this mountainous ecosystem. Furthermore, fine-scale data on the present distribution and abundance of invasive plant species are important to determine future quantitative changes in Mount Pohen that 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 ten invasive plants recorded in the research sites, Ageratina riparia and Austroeupatorium inulaefolium were the most abundant and widespread; revealing a highest 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 climate change.

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