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https://doi.org/10.1007/s12224-025-09463-2

Species richness and distribution of alien plant species in Kinabalu Park, Malaysia

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Received: 26 February 2024 / Revised: 18 February 2025 / Accepted: 28 March 2025

Abstract Kinabalu Park, Malaysia's first World Heritage Site, faces a persistent threat from invasive alien species, which negatively impact its rich biodiversity. The lack of systematic studies on alien plant species in the park hinders the effective management of invasive alien species. This study aims to establish a baseline by determining the species richness and distribution of alien plant species on the southern slope of Mount Kinabalu. Sampling was conducted at three sites with intensive tourism activities: the Kinabalu Park (KP) headquarters complex (14 plots), the Mesilau substation (12 plots), and along the Summit trail (10 plots). In total, 344 specimens were identified as alien plant species, belonging to 98 species from 39 families. Of these, 65 species are classified as invasive alien species based on previous reports. The KP headquarters complex exhibited the highest species richness (91 species), followed by the Mesilau substation (21 species) and the Summit trail (9 species). The majority of alien plant species belonged to the families Asteraceae, Poaceae and Asparagaceae. The three most widespread alien plant species were *Hypochaeris radicata* (63.9%), *Plantago major* (52.8%) and *Crassocephalum crepidioides* (50%). This study provides the first alien plant species checklist and distribution data for Kinabalu Park, offering a crucial reference for future studies and management plans.

Keywords Alien plant species · Invasive alien species · Mount Kinabalu · Species richness · Tropical montane forest

Introduction

Invasive alien species (IAS) are a source of concern because they pose a severe threat to natural ecosystems by negatively affecting biological diversity (Senator and Rozenberg 2017; Kumar Rai and Singh 2020; Pyšek et al. 2020). IAS are organisms introduced, either deliberately or accidentally, outside their native environments, and they pose threats to ecosystems, economies (Pimentel et al. 2005; Olson 2006) and even human health (Keller et al. 2011). They frequently outcompete native species, prey on them or introduce diseases, leading to a reduction in biodiversity. Human-mediated dispersal is one of the

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12224-025-09463-2.

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Published online: 28 April 2025

significant factors that contributes to the existence and global distribution of IAS. The four-T rule that determines the paths of most IAS are trade, transportation, travel, and tourism (Senator and Rozenberg 2017).

Currently, IAS is one of the 17 targets in Malaysia's National Policy of Biological Diversity 2016–2025. In particular, Target 11 states, 'By 2025, invasive alien species and pathways are identified, priority species controlled, and measures are in place to prevent their introduction and establishment.' Furthermore, Malaysia's National Action Plan on Invasive Alien Species (NAP IAS) 2021–2025 highlights the efforts and strategies to conserve and manage the rich biodiversity from IAS. Nevertheless, Malaysia needs a more robust legislative framework to regulate and reduce the effects of IAS and a massive campaign to raise public awareness of the threat of IAS on the environment.

The term 'alien plant species' (APS) refers to non-native plants introduced to new areas where they do not naturally occur, with the potential to disrupt local ecosystems. The process of an APS becoming invasive unfolds through several stages. Initially, the APS is introduced into a new environment. If it manages to survive and reproduce, it becomes established and self-sustaining. As the plant adapts to local conditions, it becomes naturalized. Eventually, the APS can become invasive, spread widely, outcompeting native species and leading to significant ecological, economic, or health-related issues (Blackburn et al. 2011). Comparatively, the invasion rate of APS is higher in tropical regions than in temperate regions (Daehler 2009). Tropical mountains are the world's most essential diversity hotspot (Bussmann 2002; Silveira et al. 2019) and are home to a diverse range of rare, endemic, and endangered flora and fauna. Nevertheless, mountain ecosystems are under increasing pressure from the introduction of IAS and climate change-driven expansion or reduction of native species along elevational gradients, which can alter the ecosystem dynamics (Guo et al. 2018). Ultimately, APS threaten the biodiversity, ecosystems and economy of most tropical mountain ranges worldwide (Daehler 2005; Bitencourt et al. 2016). Given the potential impact of APS on ecosystem functioning, ecological processes and native diversity (Charles and Dukes 2007; Theoharides and Dukes 2007), great attention should be given to enhancing invasion risk management, typically in tropical mountain ecosystems.

Mount Kinabalu is Malaysia's most famous and species-diverse tropical mountain. Situated in the country's eastern territory of Sabah, it is the highest peak in Southeast Asia and is renowned both locally and worldwide as a biodiversity hotspot, given its rich flora and mountaineering opportunities (Abdul Latip et al. 2020). As a popular destination for tourism, a large part of Mount Kinabalu is managed and protected under the Kinabalu Park World Heritage Site of the United Nations Educational, Scientific and Cultural Organization (UNESCO). The park has five main focal areas comprising biological and physical resource conservation, scientific research and educational value enhancement, recreational and tourism activities, cultural and historical value preservation, and management procedures to support other strategic thrusts (Beaman et al. 2003).

Similarly to many tropical mountain ecosystems, APS are one of the significant threats to Kinabalu Park. Because it is a World Heritage Site, the essential requirement is to ensure that the flora and fauna in Kinabalu Park are free of any species of foreign origin. The International Union for Conservation of Nature (IUCN) World Heritage Outlook 3, published on 2 December 2020, summarizes the most significant conservation challenges in Kinabalu Park as a World Heritage Site as follows: 'The absence of an up-to-date management plan and the lack of formal monitoring, assessments, and reporting reduce the ability of the management authority to identify and address emerging threats…' (IUCN World Heritage Outlook 2020).

Furthermore, the substantial risk of APS was mentioned in Sabah Parks Enactment 1984 Part VIII, 48. (f) and Part X, 58. (3), 'to must not introduce alien species vegetation into a Park or Nature Reserve and it must be destroyed…'. In line with the state legislation, the park management has imposed various economic efforts over the past ten years to eradicate the false dandelion (*Hypochaeris radicata*) from the family Asteraceae, which has been recognized as the worst invasive APS throughout Kinabalu Park. The plant was initially undetected in the upland areas of Kinabalu Park in the early 1980 s (K. Kitayama pers. commun.). However, its rapid dispersal, particularly on the Summit trail to a high elevation of ca. 3,675 m a.s.l. in the Sayat-Sayat Control Post area, has

recently raised concerns over its potential risk (IUCN World Heritage Outlook 2020). Although thousands of kilograms of *H. radicata* were collected during each eradication programme organized by the park management, the proliferation of the invasive plant remains unsolved (Ruben 2011). In recent years, Sabah Parks has remained dedicated to addressing the issue of invasive species through ongoing eradication programmes and scientific research (Olivia 2022; Justine et al. 2024; Stephanie 2024a, 2024b).

The lack of systematic studies on APS in Kinabalu Park has made it challenging to develop an effective management plan for monitoring, controlling and eradicating APS throughout the park. Furthermore, the invasion history and distribution of APS, as well as their impacts across elevation gradients on ecosystem services in tropical mountains, particularly in Mount Kinabalu, remain poorly understood. Given the importance of Kinabalu Park as a tourist destination and its crucial role in conserving unique biodiversity, including rare and endangered species, it is essential to establish baseline information. This will support the design of practical management plans for monitoring, controlling and eradicating APS within the park.

This study serves as an initial step in assessing the extent of APS establishment in Kinabalu Park, particularly in areas with intensive tourism activities. It aims to address key questions such as which APS are present at three locations within the Kinabalu Park, where are APS most prevalent, and which species are found more frequently? This baseline study also opens the door for future research on selected APS, including their distribution, spread, ecology and impacts on the local ecosystem and native species, with a focus on long-term monitoring. Therefore, the checklist provided in this study is crucial for the future development of more effective management strategies to control and eradicate invasive APS, ultimately helping to preserve the unique biodiversity of Kinabalu Park.

Material and methods

Study area

Kinabalu Park was established in 1964 as a protected national park and declared Malaysia's first UNESCO World Heritage Site on 2 December 2000. Located in the Malaysian state of Sabah on the island of Borneo, the park covers an area of approximately 754 km^2, which includes parts of three districts of Sabah: Ranau, Kota Belud, and Kota Marudu (Fig. 1). Mount Kinabalu is located within Kinabalu Park and is the highest mountain between the Himalayas and New Guinea, standing at 4,095 m a.s.l. The mountain features several types of forests, ranging from tropical lowland and hill rainforest to tropical montane forest and sub-alpine forest and scrub. It also features steep slopes, diverse geology and periodic climatic oscillations, making it a perfect area for speciation (Kitayama et al. 2014). Remarkably, Mount Kinabalu is home to a rich diversity of flora and fauna, which varies according to different elevational zones.

Kinabalu Park, and Mount Kinabalu in particular, has been a significant tourist attraction since its establishment due to its exceptional natural beauty, unique biodiversity, cultural significance and status as a UNESCO World Heritage Site. From a mere 879 visitors in 1965, the number of visitors increased significantly over the years to 313,029 visitors in 2019 (Wong and Phillipps 1996; Sabah Parks 2023). Most visitors came from outside Sabah, with approximately one-fifth being international tourists. The Mesilau substation alone recorded 19,393 visitors in 2014 (Sabah Parks 2020). However, the station was officially closed in 2015 due to significant damage to the park's infrastructure following the 6.0 magnitude earthquake that struck the region.

This study was conducted at three study sites of the areas most heavily utilized by tourists at Mount Kinabalu, Sabah, namely (i) the KP headquarters complex, (ii) the Mesilau substation, and (iii) the Summit trail (Fig. 1). KP headquarters complex is located at an approximate elevation of 1,500 m a.s.l. and is situated in lower montane forest with a mean annual temperature of 20℃ and a mean annual rainfall of 2,300 mm (Kitayama et al. 2014). By contrast, the Mesilau substation is located at the southeast corner of Mount Kinabalu and approximately 17 km from KP headquarters complex. The substation is at an elevation of around 2,000 m a.s.l. within the mossy cloud and upper montane forest and boasts a great variety of vegetation. The area also experiences much cooler temperatures with an average annual temperature range of 12.1–16.5℃. Furthermore, the Summit trail is the main route for most climbers to

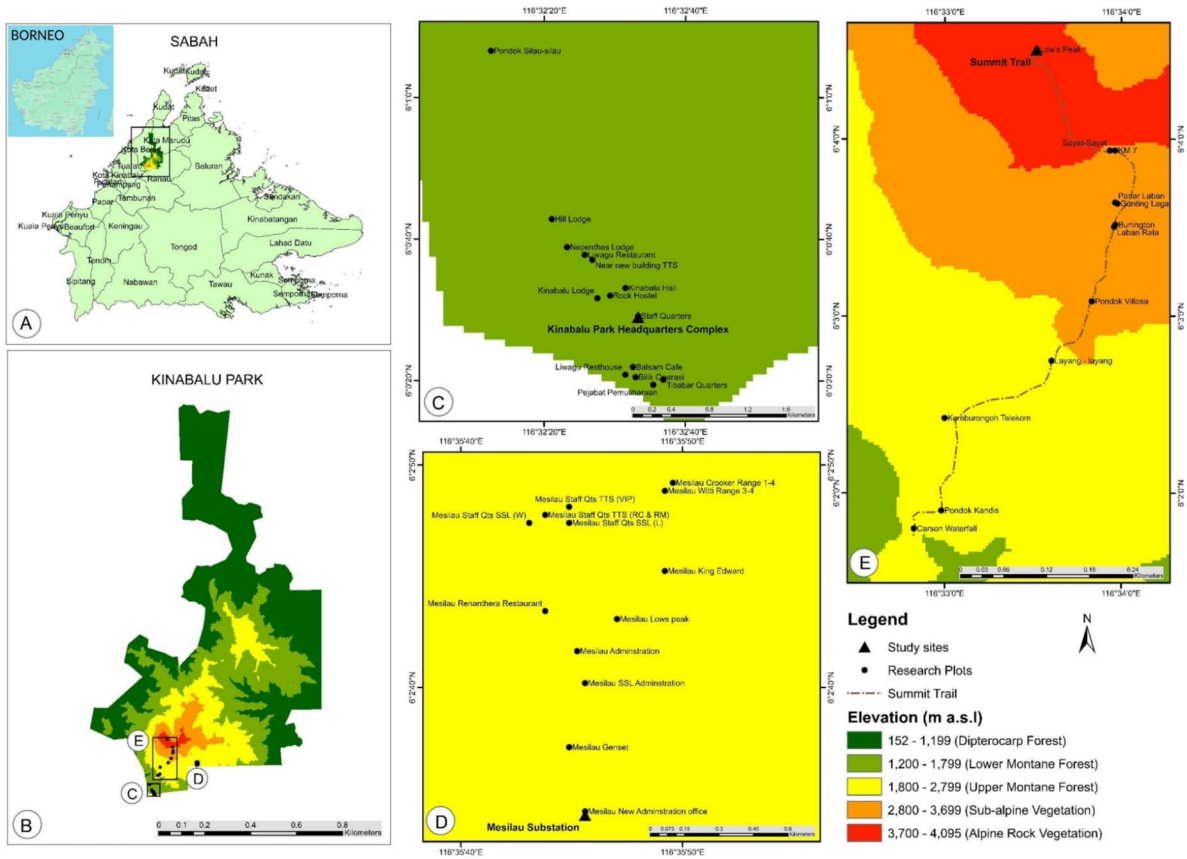

Fig. 1 Location of research plots in Kinabalu Park, Sabah. A – Map of Sabah, Malaysia. B – Map of Kinabalu Park. C – Kinabalu Park headquarters complex (14 plots). D – Mesilau substation (12 plots). E – Summit trail (10 plots)

Mount Kinabalu. The trail begins at the Timpohon Gate (approximately 4 km KP headquarters complex) at an elevation of 1,850 m a.s.l. and leads to Low's Peak (the highest peak) at 4,095 m a.s.l.

The KP headquarters complex and the Summit trail are frequently visited by tourists and are renowned for their established trails, a diverse range of accommodation options, and rich natural biodiversity. By contrast, the Mesilau substation has less tourism infrastructure and fewer visitors than the other two locations. It serves as a primary entrance to the Mesilau Trail for climbing Mount Kinabalu and as a lodging facility. The diversity of unique flora and fauna at different climate zones of Mount Kinabalu change with increasing elevation, from lowland dipterocarp forest to the summit zone and stunted bushes. The environmental conditions in these climate zones are characterized by a lower average annual temperature range of 4.9–12.1 °C (Kitayama 1992). These factors pose a challenging environment for plant growth, exacerbated by high wind velocity and low soil fertility. Consequently, the diversity of plant species that could survive and flourish within this harsh climate zone is severely limited.

Study design and plant sampling

This study aimed to assess the richness and distribution of APS in three high-tourism locations on Mount Kinabalu: the KP headquarters complex, the Mesilau substation and the Summit trail. These areas were selected to maximize coverage in terms of elevation, forest types and soil conditions while focusing on zones with intensive tourism activities. A total of 36 plots were established: 14 plots at the KP headquarters complex, 12 plots at the Mesilau substation

and 10 plots along the Summit trail. Each plot had a radius of 25 m, and the placement of plots was designed to cover as much area as possible within each location.

Given the heterogeneity of Mount Kinabalu's geology, vegetation and elevation, the sampling design aimed to capture the overall richness and distribution of APS across diverse environments. However, the objective of this study was not to address specific ecological questions or test hypotheses related to these environmental factors. Instead, the focus remained on gathering broad, representative data on APS presence within these varied habitats. Plant sampling was carried out between 2 and 26 February 2021. The presence of APS and the respective geographic coordinates (latitude, longitude) were recorded for each plot.

During fieldwork, potential APS—whether intentionally planted as food crops, ornamentals, or naturally spread—were initially identified within each plot. Specimens that were either suspected or confirmed to be APS were collected for further analysis. Upon return to the laboratory, each specimen was carefully examined, and only those confirmed as APS were retained. These verified APS specimens were then kept as voucher specimens in the Sabah Parks Herbarium (SNP).

Alien plant species identification and invasiveness assessment

The identification of APS followed a systematic approach to determine whether the species were native or alien to Kinabalu Park. Multiple resources were consulted, including the comprehensive work of Chen (2008), mobile application tools and the expertise of Sabah Parks' in-house botanists. Collections from the SNP, established in 1981, were also instrumental in confirming the native or alien status of species. Given Kinabalu Park's extensive botanical documentation since 1851 (Beaman 2005), they provided a crucial baseline for distinguishing between native and introduced species. This baseline, built on herbarium specimens and historical research, guided the identification process. Once a species was confirmed as alien and identified by Sabah Parks' botanists, its scientific name was verified using the World Flora Online (WFO 2024) to ensure consistency in nomenclature.

To assess the invasiveness of the confirmed APS, various global and regional databases were consulted. These included resources such as the BioPortal of the Naturalis Biodiversity Center (Naturalis Biodiversity Center 2022), the digital herbarium of Meise Botanic Garden (Botanical Collections 2022), the Global Biodiversity Information Facility (GBIF 2022) and the Kew Herbarium Catalogue (Royal Botanic Gardens, Kew 2022). Additional reports and sources, including Pallewatta et al. (2003), Swearingen and Bargeron (2016), Faridah-Hanum and Latiff (2021), Centre for Agriculture and Biosciences International (CABI 2024) and Global Invasive Species Database (GISD 2024), were referred to determine the invasive status of each species within Malaysia and globally. All APS specimens were preserved using standard herbarium methods, as outlined by Maden (2004). These methods included drying, pressing, mounting on paper and labelling with essential details such as species name, location and voucher number. The specimens were then stored in the SNP for future reference.

Data analysis

The final APS data were organized into a matrix of 98 species by 36 plots, with each cell representing the presence (1) or absence (0) of a species in each plot across the three locations. The species richness was then calculated, referring to the total number of species for each location (Chao et al. 2014; Hsieh et al. 2016). To identify the most frequently encountered APS, we calculated the percentage frequency for each species. This was done by dividing the number of plots where each APS was present by the total number of plots (36) and then multiplying by 100. This measure helped determine which species were the most widespread across the three study locations, providing insight into species dominance and distribution patterns.

To evaluate the adequacy of the sampling effort and assess species richness across the study sites, we employed the 'iNEXT' package in R v. 4.1.2 (R Core Team 2021). Coverage-based rarefaction and extrapolation curves were generated to estimate sampling completeness. These curves allowed us to determine whether the sampling effort was sufficient to capture the majority of APS present in the study areas and to compare species richness across the different locations, accounting for variations in sampling effort.

Results

A total of 404 specimens were collected during the fieldwork and successfully identified to the species level. Among these, 344 were identified as alien plants, representing 98 different APS from 39 families (Table S1 in the electronic supplementary material). Notably, a significant portion of these alien plants, 65 out of 98 APS, were classified as invasive based on previous reports (Pallewatta et al. 2003; Swearingen and Bargeron 2016; Faridah-Hanum and Latiff 2021; CABI 2024; GISD 2024). Table 1 provides twenty of the most prominent APS across the study sites, detailing their families, invasive status and percentage frequency.

Asteraceae is the most represented family with twenty species (20% of all APS). Poaceae and Asparagaceae follow with seven species each (7.14%). Asteraceae are present in 32 out of the 36 plots accounting for 88.9% of the study plots, followed by Plantaginaceae (52.8%; Table S2 in the electronic supplementary material).

In terms of floral origin regions (Table S3 in the electronic supplementary material), 45 APS are from the Neotropical region (South and Central America), 26 from the Palaeotropical region (tropical Asia and the Indian subcontinent), 26 from the Boreal (Holarctic) region (North America, East Asia, and Europe) and one species from the South African (Capensic) region. This corresponds to 46%, 26.5%, 26.5% and 1%, respectively.

The APS inventory's sampling completeness at the KP headquarters complex and Mesilau substation is over 83%, while that of the Summit trail is at 64% (Fig. 2). Species richness in the KP headquarters complex, Mesilau substation, and the Summit trail were 91, 21 and 9 species, respectively (Fig. 3).

Based on Fig. 4, the highest APS richness was recorded in the staff quarters (59 species), followed by the Tibabar quarters (27 species) and the Rock

Table 1 Most prominent alien plant species identified across the study sites in Kinabalu Park, Sabah

Species	Family	Invasive status*	Percentage frequency [%]
Hypochaeris radicata L.	Asteraceae	Invasive	63.9
Plantago major L.	Plantaginaceae	Invasive	52.8
Crassocephalum crepidioides S.Moore	Asteraceae	Invasive	50.0
Polygala paniculata L.	Polygalaceae	Invasive	38.9
Bidens pilosa L.	Asteraceae	Invasive	36.1
Impatiens balsamina L.	Balsaminaceae	Invasive	33.3
Elephantopus mollis Kunth	Asteraceae	Invasive	25.0
Emilia fosbergii Nicolson	Asteraceae	Invasive	25.0
Ipomoea tricolor Cav.	Convolvulaceae	Invasive	25.0
Erigeron canadensis L.	Asteraceae	Invasive	22.2
Physalis minima L.	Solanaceae	NA	22.2
Pleroma urvilleanum (DC.) P.J.F.Guim. & Michelang.	Melastomataceae	NA	22.2
Sonchus asper (L.) Hill	Asteraceae	Invasive	22.2
Chlorophytum comosum (Thunb.) Jacques	Asparagaceae	NA	19.4
Flagellaria indica L.	Flagellariaceae	NA	19.4
Rosa pendulina L.	Rosaceae	Invasive	19.4
Cardamine flexuosa With.	Brassicaceae	Invasive	16.7
Cuphea hyssopifolia Kunth	Lythraceae	Invasive	16.7
Dracaena trifasciata (Prain) Mabb.	Asparagaceae	NA	16.7
Miconia crenata (Vahl) Michelang.	Melastomataceae	Invasive	16.7

NA not available

* Based on previous reports such as Pallewatta et al. (2003), Swearingen and Bargeron (2016), Faridah-Hanum and Latiff (2021), CABI (2024) and GISD (2024).

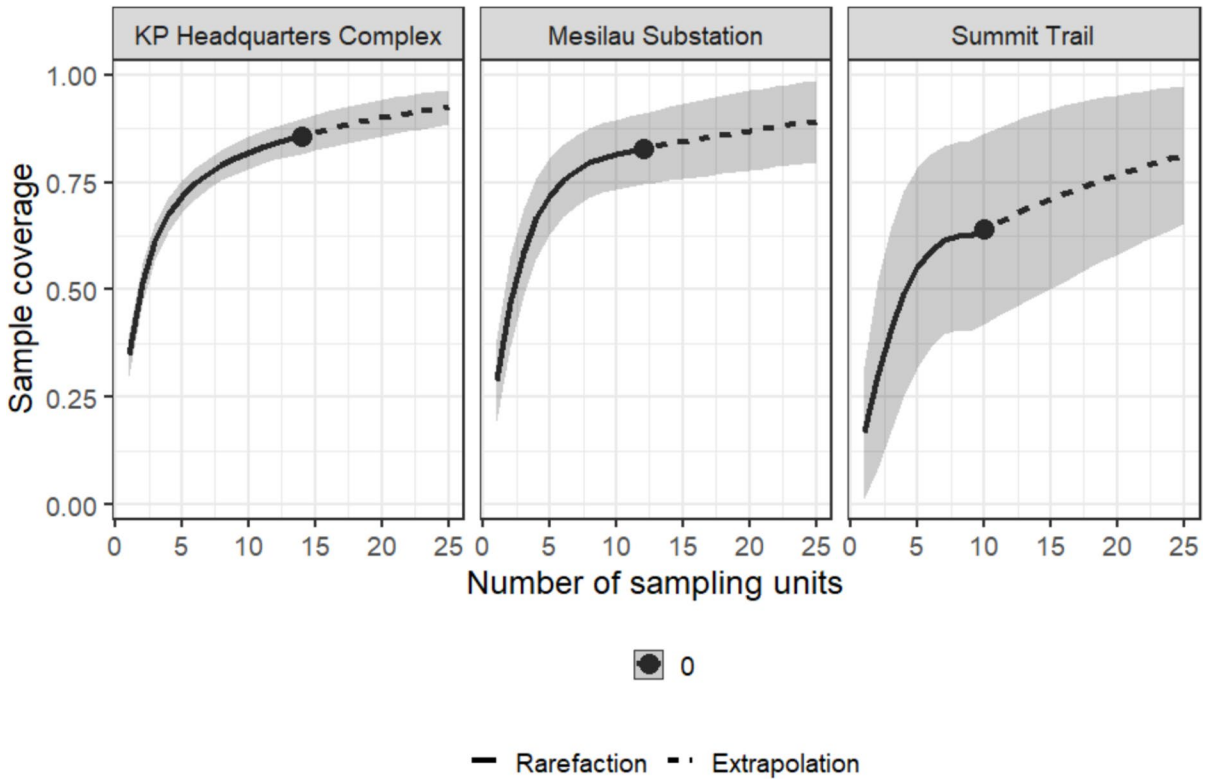

Fig. 2 Sampling completeness at the Kinabalu Park headquarters complex (0.85), the Mesilau substation (0.83) and the Summit trail (0.64)

hostel (25 species). By contrast, the lowest number of species (one species) was recorded in ten plots within the three zones.

The three most widespread APS in all three study sites are *Hypochaeris radicata* (23 plots – 63.9%; Fig. 5A), *Plantago major* (19 plots – 52.8%; Fig. 5B), *and Crassocephalum crepidioides* (18 plots – 50%; Fig. 5C). Specifically, *H. radicata* population was detected at 11 plots in the KP headquarters complex, eight plots in the Mesilau substation and four plots in the Summit trail with the highest elevation, ca 3,675 m at KM 7 (Sayat-Sayat Control Post). Meanwhile, *P. major* populations were discovered at eleven plots in the KP headquarters complex, five plots in Mesilau substation, and three plots in the Summit trail with the highest elevation, ca 3,277 m a.s.l., near the Burlington (Panalaban substation). Furthermore, the population of *C. crepidioides* was detected at thirteen plots in the KP headquarters complex, four plots at the Mesilau substation, and one plot in the Summit trail, with the highest elevation of ca 2,260 m at Kemburongoh Telekom.

Three of the APS identified in this study are listed among the 100 worst IAS in the world (Luque et al. 2013), namely *Imperata cylindrica* (Poaceae), *Miconia crenata* (Melastomataceae) and *Lantana camara* (Verbenaceae). In particular, *I. cylindrica* was recorded only in one location at the Mesilau substation whereas *M. crenata* and *L. camara* were recorded in six and three locations at the KP headquarters complex, respectively.

Discussion

Checklist and richness of alien plant species

This study presents the first comprehensive checklist of alien plant species in Kinabalu Park, identifying 98 species encompassing treelets, shrubs, herbs, creepers and grasses. Among the three heavily frequented

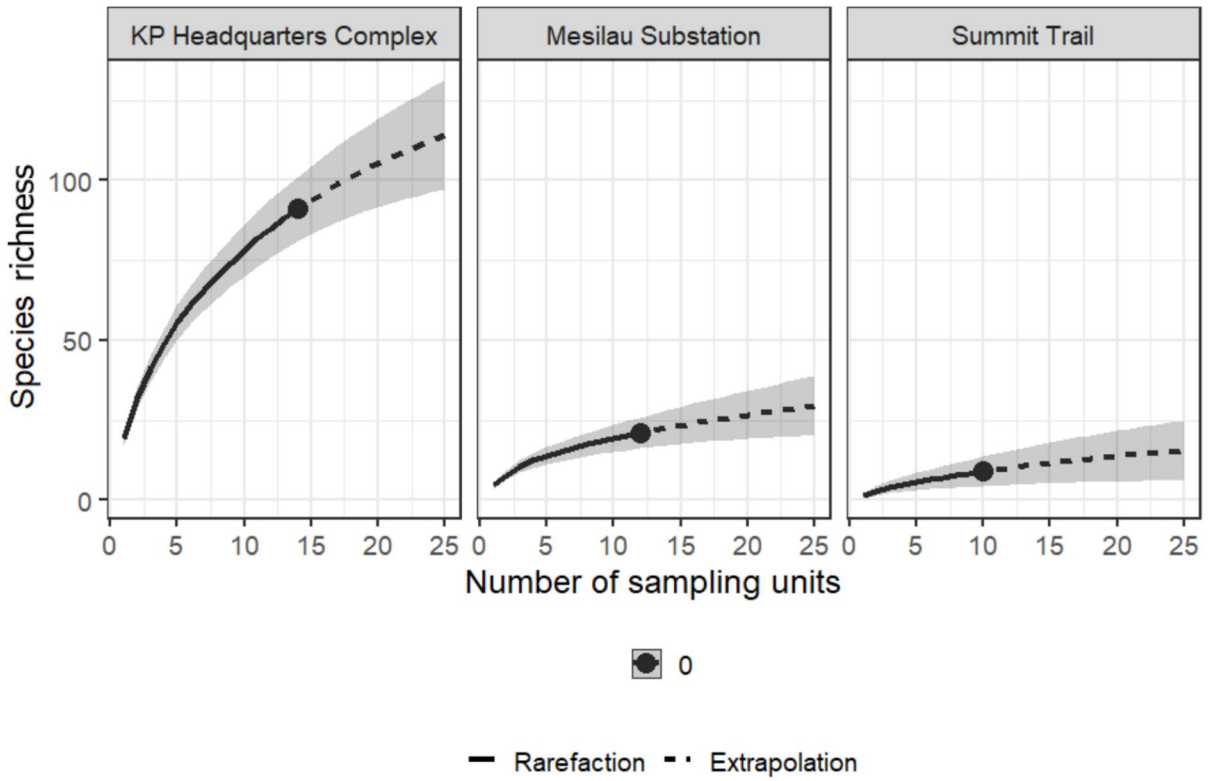

Fig. 3 Species richness in the Kinabalu Park headquarters complex (91 species), the Mesilau substation (21 species), and the Summit trail (9 species)

tourist sites (the KP headquarters complex, the Mesilau substation and the Summit trail) spanning elevations from 1,470 to 3,940 m a.s.l., the KP headquarters complex exhibited the highest species richness with 91 recorded species.

The Asteraceae family was particularly prevalent, detected at 32 out of 36 localities (approximately 88.9% of study sites), reflecting its adaptability to various ecosystems (Panero and Funk 2008). Notably, the most widespread species from this family were *Hypochaeris radicata* (false dandelion), *Crassocephalum crepidioides* (redflower ragleaf) and *Bidens pilosa* (black-jack). The dominance of these species can be attributed to their ecological flexibility and competitive growth strategies. For example, *H. radicata* thrives in disturbed soils, often outcompeting native flora. Similarly, *C. crepidioides* and *B. pilosa* are known for their rapid colonization abilities. Additionally, they are aggressive and weedy species with small seeds that can be easily dispersed by wind. These characteristics as align with common IAS traits, including high dispersal efficiency, prolific reproduction, tolerance to a wide range of environmental conditions, and rapid growth, all of which facilitate their adaptation in non-origin habitats (Fletcher et al. 2019).

Furthermore, three of the IAS (*Imperata cylindrica*, *Miconia crenata* and *Lantana camara*) are listed among the top 100 worst invasive species globally. This high proportion of invasive species underscores the significant threat they pose to the region's biodiversity and ecological integrity. The widespread occurrence of *H. radicata*, which was found in 63.9% of the total study plots, especially in open areas and near tourism facilities is particular concerning. These species are known to cause ecological harm by outcompeting the native flora (Peters 2001; Lucardi et al. 2020), necessitating early detection and rapid response strategies. With 98 APS recorded, of which 65 species are classified as invasive based on previous reports, Kinabalu Park surpasses other regions such as Gunung

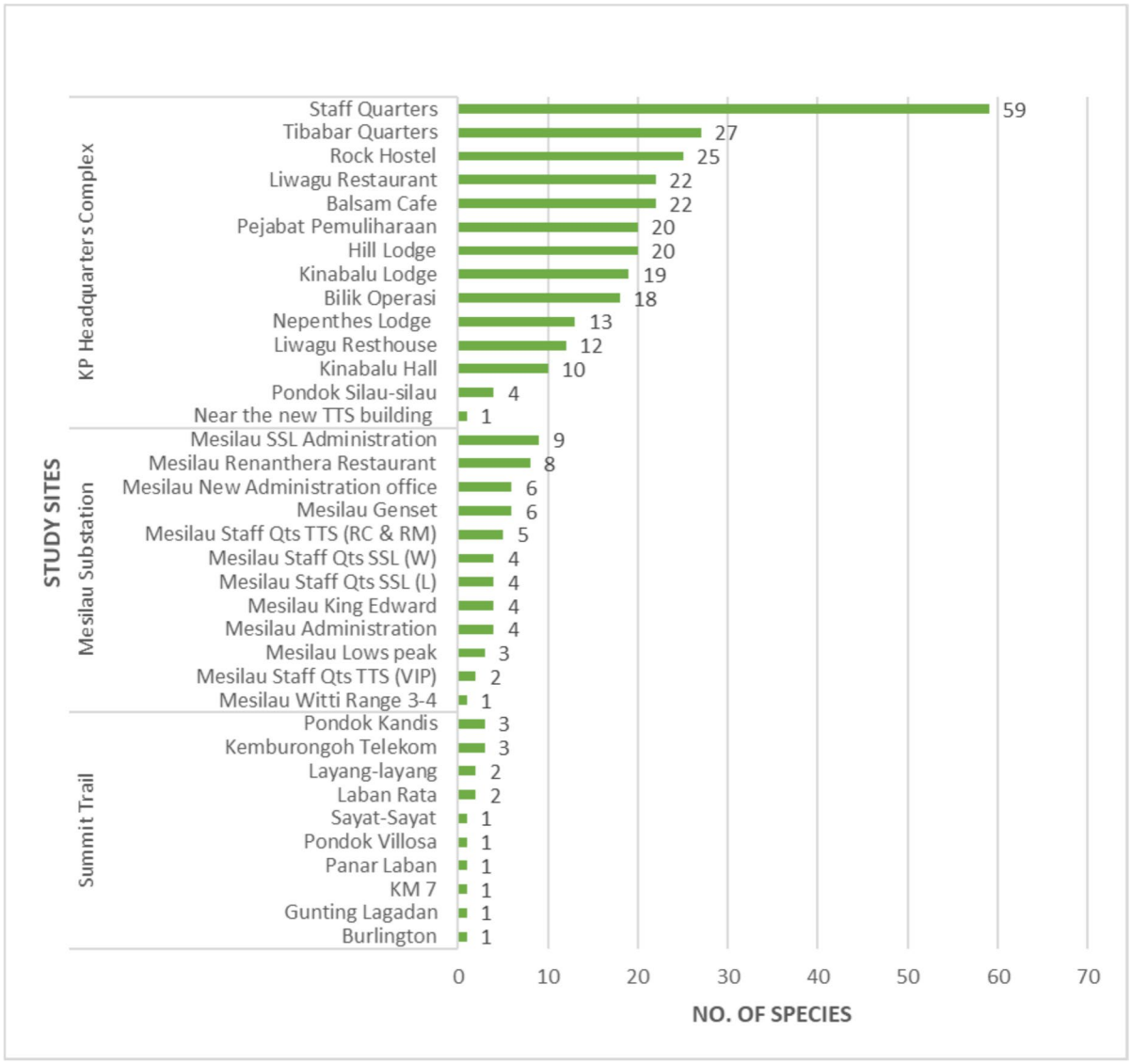

Fig. 4 The number of alien plant species at each plot within the three study sites in Kinabalu Park

Gede-Pangrango, Gunung Merapi, Gunung Merbabu, and Bromo Tengger Semeru in Indonesia, which has 41 invasive species (Padmanaba et al. 2017), as well as Arunachal Pradesh and Assam in India, which report 18 invasive species (Kosaka et al. 2010). By contrast, Himachal Pradesh in India reports a higher number of APS at 425 species (Ahmad et al. 2018), which may be attributed to its broader elevation range (300–4,900 m a.s.l.) and more extensive anthropogenic influences.

Influence of environmental and anthropogenic factors

Environmental factors, such as the climate, elevation, habitat diversity and disturbance, significantly influence the distribution of APS (Panitsa et al. 2018). The largest proportion of APS in Kinabalu Park originate from the Neotropical region (46%). This pattern may be explained by the similarity in climatic and environmental conditions between the Neotropical region and Mount Kinabalu's tropical mountain climate. The

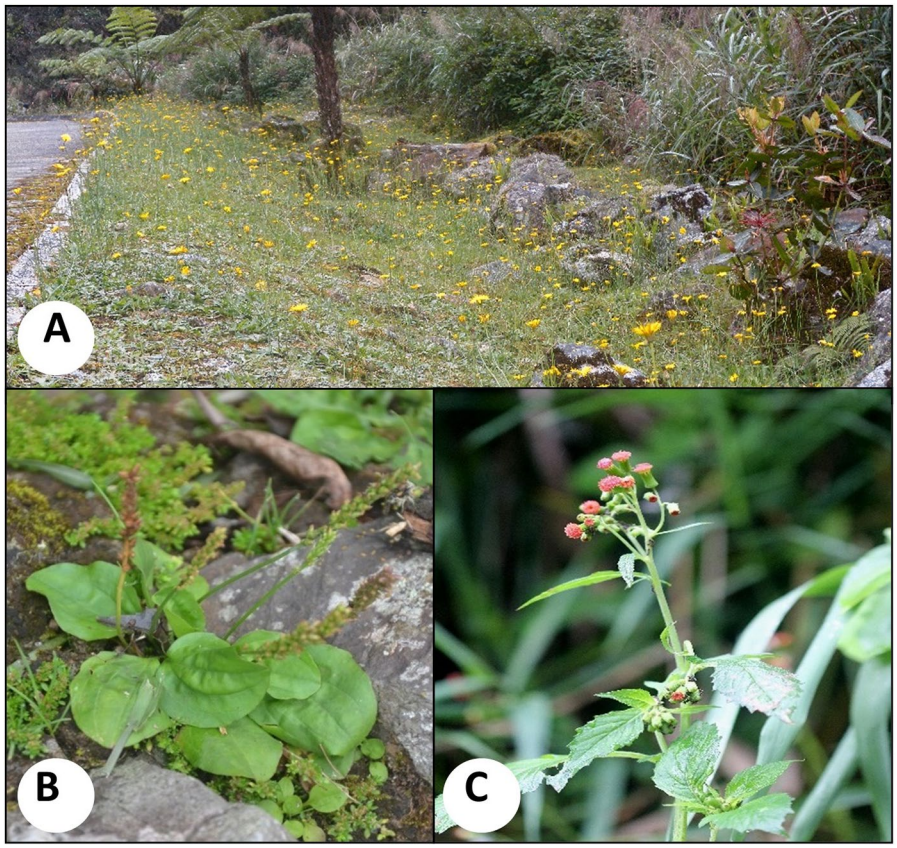

Fig. 5 The three most widespread alien plant species in Kinabalu Park, Sabah. A – *Hypochaeris radicata* (false dandelion). B – *Plantago major* (broad-leaf plantain). C – *Crassocephalum crepidioides* (redflower-ragleaf)

Neotropical region, encompassing tropical areas of the Americas, including parts of Central and South America, shares similar climates with Southeast Asia. Both regions experience warm temperatures, high humidity and substantial rainfall (Corlett and Primack 2006; Groves 2022), making Neotropical plant species pre-adapted to thrive in conditions like those found in Kinabalu Park. Additionally, many Neotropical plants are adapted to mountainous terrains and can tolerate a wide range of elevations (Cuesta et al. 2017), increasing their potential to successfully establish in the diverse elevational zones of the park.

The high richness of APS at the KP headquarters complex appears to result from a combination of factors. First, its lower elevation compared to the Mesilau substation and the Summit trail provides more favourable conditions, such as higher temperatures and increased resource availability, which typically support a greater diversity of plant species (Grytnes and McCain 2013). Secondly, the KP headquarters complex experiences higher levels of human activity, both from tourism and park management operations. Being the first area to open to visitors, it has had a longer duration of exposure to human influence and receives more visitors than the other sites. This increased human presence facilitates the introduction and spread of APS through pathways such as accidental seed dispersal, disturbance of native habitats, and intentional planting of ornamental species (Bakar 2004).

The proximity to human settlements and tourism facilities significantly contributes to the proliferation of APS. The extensive distribution of APS near the staff quarters in the KP headquarters complex, where 59 species were recorded, underscores the impact of human activities. Similar patterns have been observed elsewhere, where increased human population density and associated disturbances significantly affect APS richness (Dimitrakopoulos et al. 2022; Yang et al. 2022; Justine et al. 2024; Šipek and Šajna 2020, 2024).

Whereas the Summit trail and the Mesilau substation also host tourist activities, their higher elevations and harsher environmental conditions—particularly

at the Summit trail, with different forest types, vegetative structures, and soil types along the elevation gradient—may hinder APS establishment and proliferation. These factors result in lower overall species richness of APS in these areas, as APS often struggle to adapt to the more specialized and less hospitable conditions found at higher elevations (Becker et al. 2005).

Management implications

The KP headquarters complex, with its high species richness of APS, is a critical area for monitoring and management efforts. Targeted strategies should focus on preventing the establishment and further spread of APS in this rich habitat to protect native biodiversity. The twenty most prominent APS listed in Table 1 provide essential insights for park managers, allowing them to prioritize control efforts on the most aggressive and widespread invasive species. Management should also concentrate on the most prevalent species using cost-efficient mitigation approaches (Nel et al. 2004). Despite Kinabalu Park's designation as a World Heritage Site, its protected status alone is insufficient to safeguard against the threats posed by APS. Active management measures are essential (Clout 2001; Bissessur et al. 2017).

Strengthening management efforts requires enhancing early detection and rapid response (EDRR) strategies to identify and control APS before they become widespread and cause significant ecological harm. This can be achieved by incorporating innovative technologies such as environmental DNA (eDNA) analysis (Larson et al. 2020), which allows for the detection of species through soil or water samples without the need for direct observation. Furthermore, unmanned aerial vehicles (UAVs) equipped with remote sensing technologies can improve monitoring in challenging terrains (Papp et al. 2021; Royimani et al. 2019). Prioritizing EDRR in high-risk areas, such as trails and park entry points, alongside targeted mechanical removal—such as mowing, cutting, or uprooting—can greatly enhance invasive species management efforts (Cutway 2017; Flory and Clay 2009). For smaller infestations, manual or mechanical removal methods can be highly effective, particularly for species that are easy to uproot or cut. Some Asteraceae species, particularly those with deep perennial roots, like *H. radicata* (Aarssen 1981), are easier to remove on rainy days when softer soils facilitate full root extraction. Complete removal under these conditions prevents regrowth and enhances control effectiveness. Moreover, public awareness campaigns and community involvement in monitoring and removal initiatives can help improve surveillance, prevent the introduction and spread of invasive species, and reduce management costs (Shackleton et al. 2019).

In Kinabalu Park, several management strategies have been implemented, with a focus on controlling the spread of the most prevalent APS, *Hypochaeris radicata*. An annual eradication programme is carried out, involving local communities and stakeholders in the manual removal of *H. radicata*. This initiative is complemented by public awareness campaigns to foster community engagement and understanding of the invasive species issue (Ruben 2011; Olivia 2022; Justine et al. 2024; Stephanie 2024a, 2024b).

Future research

The raw data collected in this research serves as a foundation for creating digital maps that offer a comprehensive overview of the distribution, abundance and characteristics of IAS in the park. Leveraging this data, along with other relevant ecological information, will enable more precise and targeted management efforts. It is recommended to develop digital mapping tools to track the presence of APS, monitor growth and expansion rates, and assess treatment efficiency (Bolch et al. 2020).

Sampling completeness varied among the study sites, with the KP headquarters complex and the Mesilau substation achieving over 83% completeness, but only 64% in the Summit trail. The lower completeness in the Summit trail indicates challenges in surveying areas with complex terrains and environmental conditions. More systematic surveys along the elevation gradients, particularly along the trails, are needed to obtain a complete picture of APS distribution.

Future research should concentrate on understanding the invasion processes and ecological impacts of APS on native biodiversity (e.g. Pritekel et al. 2006; Lazzaro et al. 2020), particularly in mountain ecosystems where species are often highly specialized and sensitive to disturbances. Investigating factors influencing the rate of plant invasion—including historical

introductions, pathways of spread, and the role of climate change (e.g. Theoharides and Dukes 2007; Ricciardi et al. 2021)—will provide deeper insights into preventing future invasions. Additionally, studying the potential effects of global warming on APS invasion rates at higher elevations (e.g. Petitpierre et al. 2016; Shrestha et al. 2018) is crucial, as climate change may exacerbate these risks.

Conclusion

This study presents the first comprehensive checklist of alien plant species in Kinabalu Park, Malaysia, identifying 98 species, with a notable 65 classified as invasive according to previous reports. These findings provide essential reference information for developing effective management strategies and guiding future research efforts to control and eradicate invasive alien plant species in Kinabalu Park. By prioritizing areas for monitoring and focusing on the most aggressive invasive species, park managers can implement more targeted and effective actions to halt the expansion of alien plant species. Future research on Mount Kinabalu should focus on understanding the invasion processes, ecological impacts on native biodiversity, and the potential effects of climate change on the distribution of alien plant species, particularly at higher elevations. Investigating factors, such as historical introductions, pathways of spread and species-specific traits, will provide deeper insights necessary for developing long-term management solutions.

Acknowledgements The authors would like to acknowledge the Sabah Parks management, specifically the honourable Dr Maklarin Lakim and Dr Nasrulhakim Maidin for their support, guidance and permission to conduct this research. Most of all, the authors would like to thank Fred Tuh Yit Yu, Matsain Mohd Buang, Sukaibin Sumail, Kalapin Sampin, Yabainus Juhalin, Wilson Salikun, and all the staff from the Research and Education Division at Kinabalu Park for their full assistance during fieldwork and species identification. Additionally, we extend our appreciation to Dr Petr Koutecký and the four anonymous reviewers for their constructive comments and suggestions, which have significantly improved the manuscript. Sincere gratitude to the National Conservation Trust Fund for Natural Resources (NCTF) 2022 under the Ministry of Natural Resources, Environment, and Climate Change (NRECC), Malaysia, for funding this project entitled 'Ecology and Management of Invasive Alien Plant Species in Sabah Parks: Development of the First Digital Application to Monitor, Control, and Eradicate the Invasive Alien Plant Species in Kinabalu Park' (KeTSA Ref. (S) 600 - 2/1/48/7 (16)) to Sabah Parks.

Author contributions Conceptualization: VTJ, TSL, MS; Data curation: VTJ, AA, JK, HM; Formal analysis, Software and Visualization: VTJ, TSL, AA; Writing – original draft: VTJ, AA; Methodology: VTJ, TSL, MS; Data validation, Review and editing: VTJ, TSL, MS, RR; Supervision: MS, TSL; Project administration: VTJ, RR; Revision: VTJ, TSL, MS, RR.

Funding Ministry of Natural Resources, Environment, and Climate Change (NRECC) Malaysia, KeTSA Ref. (S) 600 - 2/1/48/7 (16), Vanielie Terrence Justine

Data Availability All data supporting the findings of this study are included in the appendix submitted with the manuscript.

Declarations

Ethics and security Special thanks go to the Sabah Biodiversity Centre for permission to conduct research fieldwork in Sabah, Malaysia (License Ref. No. JKM/MBS.1000 - 2/2 JLD.16 (1)).

Conflicts of interest The authors have declared that no competing interests exist. The experiments complied with the current laws of the country in which they were performed.

Appendix

Table 2 Location of plots within the three study sites in Kinabalu Park

No.	Location of plot	Study site	Elevation [approx. m a.s.l.]	Latitude (° N)	Longitude (° E)
1	Staff quarters	KP headquarters complex	1,470	6.0081	116.5426
2	Liwagu restaurant	KP headquarters complex	1,486	6.0105	116.5405
3	Kinabalu hall	KP headquarters complex	1,522	6.0092	116.5421
4	Near the new TTS building	KP headquarters complex	1,562	6.0103	116.5408
5	Balsam cafe	KP headquarters complex	1,568	6.0061	116.5424
6	Bilik Operasi	KP headquarters complex	1,571	6.0057	116.5425
7	Pejabat Pemuliharaan	KP headquarters complex	1,575	6.0054	116.5432
8	Tibabar quarters	KP headquarters complex	1,575	6.0056	116.5436
9	Rock hostel	KP headquarters complex	1,577	6.0089	116.5415
10	Liwagu resthouse	KP headquarters complex	1,583	6.0058	116.5421
11	Nepenthes lodge	KP headquarters complex	1,593	6.0108	116.5398
12	Kinabalu lodge	KP headquarters complex	1,598	6.0088	116.5410
13	Hill lodge	KP headquarters complex	1,610	6.0119	116.5392
14	Pondok Silau-silau	KP headquarters complex	1,663	6.0185	116.5368
15	Mesilau new administration office	Mesilau substation	1,785	6.0429	116.5960
16	Mesilau Genset	Mesilau substation	1,898	6.0437	116.5958
17	Mesilau staff quarters TTS (VIP)	Mesilau substation	1,919	6.0467	116.5958
18	Mesilau SSL administration	Mesilau substation	1,928	6.0445	116.5960
19	Mesilau Low's peak	Mesilau substation	1,934	6.0453	116.5964
20	Mesilau Renanthera restaurant	Mesilau substation	1,935	6.0454	116.5955
21	Mesilau King Edward	Mesilau substation	1,940	6.0459	116.5970
22	Mesilau administration	Mesilau substation	1,941	6.0449	116.5959
23	Mesilau staff quarters TTS (RC & RM)	Mesilau substation	1,945	6.0466	116.5955
24	Mesilau staff quarters SSL (W)	Mesilau substation	1,947	6.0465	116.5953
25	Mesilau staff quarters SSL (L)	Mesilau substation	1,948	6.0465	116.5958
26	Mesilau Witti range 3–4	Mesilau substation	1,955	6.0469	116.5970
27	Pondok Kandis	Summit trail	1,970	6.0317	116.5497
28	Kemburongoh Telekom	Summit trail	2,260	6.0404	116.5500
29	Layang-layang	Summit trail	2,718	6.0458	116.5601
30	Pondok Villosa	Summit trail	2,981	6.0514	116.5639
31	Laban Rata	Summit trail	3,270	6.0584	116.5660
32	Burlington	Summit trail	3,277	6.0586	116.5661
33	Panar Laban	Summit trail	3,328	6.0607	116.5661
34	Gunting Lagadan	Summit trail	3,338	6.0606	116.5663
35	KM 7	Summit trail	3,675	6.0656	116.5661
36	Sayat-Sayat	Summit trail	3,683	6.0656	116.5656

KP Kinabalu Park, *TTS Taman-Taman Sabah, RC & RM* reception centre and reception manager, *SSL* Sutera sanctuary lodges, *W* women's quarters, *L* men's quarters, *KM* kilometre

Table 3 Checklist of alien plant species in Kinabalu Park with origin and herbarium record information

No.	Family	Scientific name	Herbarium specimen No.	Study site	Location of plot	Origin (region of flora distribution)	Origin (country/continent)	Herbarium record
1	Acanthaceae	*Hypoestes phyllostachya* Baker	SNP 42198	KP headquarters complex	staff quarters	Palaeotropical	Madagascar	NA
2	Amaranthaceae	*Iresine herbstii* Hook.	SNP 42161	KP headquarters complex	Rock hostel	Neotropical	northern Peru	NA
3	Amaryllidaceae	*Allium ampeloprasum* L.	SNP 42321	KP headquarters complex	staff quarters	Boreal (Holarctic)	Macaronesia, Mediterranean to Central Asia	NA
4	Amaryllidaceae	*Allium fistulosum* L.	SNP 42087	KP headquarters complex	Nepenthes lodge	Boreal (Holarctic)	China	NA
			SNP 42199		Staff quarters			
			SNP 42626		Tibabar quarters			
5	Amaryllidaceae	*Hippeastrum reticulatum* (L'Hér.) Herb.	SNP 41575	Mesilau substation	Mesilau staff quarters SSL (W)	Neotropical	eastern Brazil to Argentina (Misiones)	NA
6	Araceae	*Caladium bicolor* (Aiton) Vent.	SNP 42189	KP headquarters complex	staff quarters	Neotropical	Central America to Argentina (Salta)	NA
7	Araceae	*Calla palustris* L.	SNP 42172	KP headquarters complex	Rock hostel	Boreal (Holarctic)	Europe to Japan, subarctic America to northern and eastern USA	NA
8	Araceae	*Dieffenbachia seguine* (Jacq.) Schott	SNP 42003	KP headquarters complex	Hill lodge	Neotropical	Caribbean to tropical South America	NA
			SNP 42144		Rock hostel			
			SNP 42325		staff quarters			
			SNP 42395		Liwagu restaurant			
			SNP 42543		Kinabalu hall			
9	Araceae	*Monstera obliqua* Miq.	SNP 42305	KP headquarters complex	staff quarters	Neotropical	Trinidad to Central and tropical South America	NA
10	Araceae	*Syngonium podophyllum* Schott	SNP 42167	KP headquarters complex	Rock hostel	Neotropical	Mexico to tropical America	L.1423384, Dalat, Sarawak, Malaysia (28 November 1989) Collector: Kandau Jenang
11	Araceae	*Zamioculcas zamiifolia* (G.Lodd.) Engl.	SNP 42185	KP headquarters complex	staff quarters	Palaeotropical	Kenya to KwaZulu-Natal	NA
12	Araliaceae	*Hedera helix* L.	SNP 42602	KP headquarters complex	Tibabar quarters	Palaeotropical	Europe to western and northern Türkiye	NA
13	Asparagaceae	*Chlorophytum comosum* (Thunb.) Jacques	SNP 42050	KP headquarters complex	Hill lodge	Palaeotropical	western tropical Africa to Cameroon, Ethiopia to South Africa	NA
			SNP 42133		Kinabalu lodge			
			SNP 42312		staff quarters			
			SNP 42424		Balsam cafe			
			SNP 42513		Liwagu restaurant			
			SNP 42569		Bilik Operasi			
			SNP 42674		Pejabat Pemuliharaan			
14	Asparagaceae	*Dracaena braunii* Engl.	SNP 42168	KP headquarters complex	Rock hostel	Palaeotropical	western central tropical Africa	NA
			SNP 42368		Liwagu restaurant			

Table 3 (continued)

No.	Family	Scientific name	Herbarium specimen No.	Study site	Location of plot	Origin (region of flora distribution)	Origin (country/continent)	Herbarium record
15	Asparagaceae	*Dracaena fragrans* (L.) Ker Gawl.	SNP 42182	KP headquarters complex	staff quarters	Palaeotropical	tropical Africa	NA
16	Asparagaceae	*Dracaena reflexa* Lam.	SNP 42318	KP headquarters complex	staff quarters	Palaeotropical	northeastern Mozambique, West Indian Ocean	K000401382, Gunung Kerbau, Perak, Malaysia (14 March 1913) Collector: Robinson, H.C.
17	Asparagaceae	*Dracaena surculosa* Lindl.	SNP 42192	KP headquarters complex	staff quarters	Palaeotropical	western central tropical Africa	Petaling, Selangor, Malaysia (29 November 1987) Collector: Richard D. Worthington
18	Asparagaceae	*Dracaena trifasciata* (Prain) Mabb.	SNP 41956	Mesilau substation	Mesilau SSL administration	Palaeotropical	southern Nigeria to western central tropical Africa, Tanzania	L.1456830, Sandakan, Sabah, Malaysia (13 October 1949) Collector: Cuadra A
			SNP 42319	KP headquarters complex	staff quarters			
			SNP 42552		Kinabalu hall			
			SNP 42567		Bilik Operasi			
			SNP 42634		Tibabar quarters			
			SNP 42669		Pejabat Pemuliharaan			
19	Asparagaceae	*Triteleia ixioides* (Dryand. ex W.T.Aiton)	SNP 42177	KP headquarters complex	staff quarters	Boreal (Holarctic)	Oregon to Mexico (North Baja California)	NA
20	Asteraceae	*Ageratum conyzoides* L.	SNP 42310	KP headquarters complex	staff quarters	Neotropical	Mexico	L.3016131, Sabah, Malaysia (01 October 1922) Collector: Elmer, ADE
			SNP 42375		Liwagu restaurant			
			SNP 42482		Liwagu resthouse			
			SNP 42664		Pejabat Pemuliharaan			
21	Asteraceae	*Artemisia vulgaris* L.	SNP 42584	KP headquarters complex	Bilik Operasi	Boreal (Holarctic)	temperate Eurasia to Indo-China, North Africa	L.3017143, Sarawak, Malaysia (28 November 1982) Collector: P. Chai & O. Ismawi
22	Asteraceae	*Bidens bipinnata* L.	SNP 42655	KP headquarters complex	Pejabat Pemuliharaan	Boreal (Holarctic)	eastern Canada to central and eastern USA and Arizona	NA

Table 3 (continued)

No.	Family	Scientific name	Herbarium specimen No.	Study site	Location of plot	Origin (region of flora distribution)	Origin (country/continent)	Herbarium record
23	Asteraceae	*Bidens pilosa* L.	SNP 41567	Mesilau substation	Mesilau staff quarters TTS (RC & RM)	Neotropical	tropical and subtropical America	L.3016828, Tawau, Sabah, Malaysia (01 October 1922) Collector: Elmer, A.D.E.
			SNP 41903		Mesilau King Edward			
			SNP 41916		Mesilau Renanthera restaurant			
			SNP 41984		Mesilau new administration office			
			SNP 42014	KP headquarters complex	Hill lodge			
			SNP 42098		Nepenthes lodge			
			SNP 42173		Rock hostel			
			SNP 42317		staff quarters			
			SNP 42415		Balsam cafe			
			SNP 42478		Liwagu resthouse			
			SNP 42592		Bilik Operasi			
			SNP 42611		Tibabar quarters			
			SNP 42924	Summit trail	Pondok Villosa			

Table 3 (continued)

No.	Family	Scientific name	Herbarium specimen No.	Study site	Location of plot	Origin (region of flora distribution)	Origin (country/continent)	Herbarium record
24	Asteraceae	*Crassocephalum crepidioides* S.Moore	SNP 41905	Mesilau substation	Mesilau King Edward	Palaeotropical	tropical and South Africa, Madagascar	L.3679412, N.Sembilan, Malaysia (23 January 1946) Collector: Monod de Froideville C
			SNP 41928		Mesilau Renanthera restaurant			
			SNP 41934		Mesilau administration			
			SNP 41946		Mesilau SSL administration			
			SNP 41995	KP headquarters complex	Pondok Silau-silau			
			SNP 42008		Hill lodge			
			SNP 42095		Nepenthes lodge			
			SNP 42113		Kinabalu lodge			
			SNP 42155		Rock hostel			
			SNP 42351		staff quarters			
			SNP 42416		Balsam café			
			SNP 42473		Liwagu resthouse			
			SNP 42551		Kinabalu hall			
			SNP 42578		Bilik Operasi			
			SNP 42619		Tibabar quarters			
			SNP 42666		Pejabat Pemuliharaan			
			SNP 42930		near the new TTS building			
			SNP 42919	the Summit trail	Kemburongoh Telekom			
25	Asteraceae	*Elephantopus mollis* Kunth	SNP 41996	KP headquarters complex	Pondok Silau-silau	Neotropical	tropical and subtropical America	L.3698866, Sandakan, Sabah, Malaysia (01 February 1920) Collector: Wood DD
			SNP 42019		Hill lodge			
			SNP 42096		Nepenthes lodge			
			SNP 42123		Kinabalu lodge			
			SNP 42151		Rock hostel			
			SNP 42460		Liwagu resthouse			
			SNP 42561		Kinabalu hall			
			SNP 42598		Bilik Operasi			
			SNP 42676		Pejabat Pemuliharaan			

Table 3 (continued)

No.	Family	Scientific name	Herbarium specimen No.	Study site	Location of plot	Origin (region of flora distribution)	Origin (country/continent)	Herbarium record
26	Asteraceae	*Emilia fosbergii* Nicolson	SNP 41558	Mesilau substation	Mesilau staff quarters TTS (VIP)	Neotropical	tropical and subtropical America	NA
			SNP 41904		Mesilau King Edward			
			SNP 41917		Mesilau Renanthera restaurant			
			SNP 41936		Mesilau administration			
			SNP 41966		Mesilau Genset			
			SNP 41980		Mesilau new administration office			
			SNP 42051	KP headquarters complex	Hill lodge			
			SNP 42135		Kinabalu lodge			
			SNP 42158		Rock hostel			
27	Asteraceae	*Erechtites hieraciifolius* (L.) Raf. ex DC.	SNP 42194	KP headquarters complex	staff quarters	Neotropical	eastern Canada to tropical and subtropical America	L.3687108, Sabah, Malaysia (01 October 1921) Collector: Elmer, ADE
			SNP 42463		Liwagu resthouse			
28	Asteraceae	*Erigeron canadensis* L.	SNP 41565	Mesilau substation	Mesilau staff quarters TTS (RC & RM)	Boreal (Holarctic)	New World	NA
			SNP 42031	KP headquarters complex	Hill lodge			
			SNP 42094		Nepenthes lodge			
			SNP 42370		Liwagu restaurant			
			SNP 42418		Balsam café			
			SNP 42467		Liwagu resthouse			
			SNP 42583		Bilik Operasi			
			SNP 42902	Summit trail	Pondok Kandis			
29	Asteraceae	*Galinsoga parviflora* Cav.	SNP 42169	KP headquarters complex	Rock hostel	Neotropical	Mexico to tropical America	L.1299379, Perak, Malaysia (10 September 1949) Collector: Sinclair J; Kiah
			SNP 42335		staff quarters			

Table 3 (continued)

No.	Family	Scientific name	Herbarium specimen No.	Study site	Location of plot	Origin (region of flora distribution)	Origin (country/continent)	Herbarium record
30	Asteraceae	*Hypochaeris radicata* L.	SNP 41560	Mesilau substation	Mesilau staff quarters TTS (VIP)	Boreal (Holarctic)	Europe to the Caucasus	NA
			SNP 41581		Mesilau staff quarters SSL (W)			
			SNP 41902		Mesilau King Edward			
			SNP 41907		Mesilau Low's peak			
			SNP 41924		Mesilau Renanthera restaurant			
			SNP 41948		Mesilau SSL administration			
			SNP 41973		Mesilau Genset			
			SNP 41982		Mesilau new administration office			
			SNP 42007	KP headquarters complex	Hill lodge			
			SNP 42097		Nepenthes lodge			
			SNP 42105		Kinabalu lodge			
			SNP 42345		staff quarters			
			SNP 42428		Balsam café			
			SNP 42465		Liwagu resthouse			
			SNP 42531		Liwagu restaurant			
			SNP 42550		Kinabalu hall			
			SNP 42572		Bilik Operasi			
			SNP 42633		Tibabar quarters			
			SNP 42643		Pejabat Pemuliharaan			
			SNP 42905	Summit trail	Kemburongoh Telekom			
			SNP 42925		Panar Laban			
			SNP 42935		Laban Rata			
			SNP 42946		KM 7			
31	Asteraceae	*Jacobaea vulgaris* Gaertn.	SNP 42340	KP headquarters complex	staff quarters	Boreal (Holarctic)	Europe to Mongolia and the Caucasus	NA

Table 3 (continued)

No.	Family	Scientific name	Herbarium specimen No.	Study site	Location of plot	Origin (region of flora distribution)	Origin (country/continent)	Herbarium record
32	Asteraceae	*Lactuca virosa* L.	SNP 42157	KP headquarters complex	Rock hostel	Boreal (Holarctic)	Madeira, Europe, Northwest Africa	NA
			SNP 42193		staff quarters			
33	Asteraceae	*Lapsana communis* L.	SNP 42171	KP headquarters complex	Rock hostel	Boreal (Holarctic)	Macaronesia, Europe to Siberia and Iran	NA
34	Asteraceae	*Petasites pyrenaicus* (Loefl.) G.López	SNP 41981	Mesilau substation	Mesilau new administration office	Boreal (Holarctic)	Central Mediterranean	NA
35	Asteraceae	*Rudbeckia laciniata* L.	SNP 42304	KP headquarters complex	staff quarters	Boreal (Holarctic)	central and eastern Canada to Central and eastern USA	NA
36	Asteraceae	*Smallanthus sonchifolius* (Poepp.) H.Rob.	SNP 42175	KP headquarters complex	staff quarters	Neotropical	western South America	NA
			SNP 42613		Tibabar quarters			
37	Asteraceae	*Sonchus asper* (L.) Hill	SNP 42017	KP headquarters complex	Hill lodge	Palaeotropical	temperate Eurasia, North Africa to Sahel and Somalia	NA
			SNP 42091		Nepenthes lodge			
			SNP 42518		Liwagu restaurant			
			SNP 42627		Tibabar quarters			
			SNP 42662		Pejabat Pemuliharaan			
			SNP 42903	Summit trail	Pondok Kandis			
			SNP 42913		Layang-layang			
			SNP 42927		Gunting Lagadan			
38	Asteraceae	*Sonchus oleraceus* L.	SNP 42665	KP headquarters complex	Pejabat Pemuliharaan	Boreal (Holarctic)	Macaronesia, Europe to the Mediterranean, the Sahara to the Arabian Peninsula	L.1821108, Ranau, Sabah, Malaysia (24 August 1987) Collector: Bousi J; Mansus Sungi; Gibot A
39	Asteraceae	*Sphagneticola trilobata* (L.) Pruski	SNP 42104	KP headquarters complex	Kinabalu lodge	Neotropical	Mexico to tropical South America and Trinidad	NA
			SNP 42150		Rock hostel			
			SNP 42350		staff quarters			
			SNP 42600		Bilik Operasi			
			SNP 42618		Tibabar quarters			

Table 3 (continued)

No.	Family	Scientific name	Herbarium specimen No.	Study site	Location of plot	Origin (region of flora distribution)	Origin (country/continent)	Herbarium record
40	Balsaminaceae	*Impatiens balsamina* L.	SNP 41582	Mesilau substation	Mesilau staff quarters SSL (L)	Palaeotropical	western and southern India, Sri Lanka	Pahang, Malaysia (08 March 1987) Collector: Richard D. Worthington
			SNP 41929		Mesilau Renanthera restaurant			
			SNP 41954		Mesilau SSL administration			
			SNP 41967		Mesilau Genset			
			SNP 42020	KP headquarters complex	Hill lodge			
			SNP 42163		Rock hostel			
			SNP 42408		Balsam café			
			SNP 42525		Liwagu restaurant			
			SNP 42547		Kinabalu hall			
			SNP 42594		Bilik Operasi			
			SNP 42628		Tibabar quarters			
			SNP 42657		Pejabat Pemuliharaan			
41	Begoniaceae	*Begonia cucullata* Willd.	SNP 42072	KP headquarters complex	Nepenthes lodge	Neotropical	Bolivia to Brazil and northern Argentina	Pahang, Malaysia (22 November 1987) Collector: Richard D. Worthington
			SNP 42128		Kinabalu lodge			
			SNP 42195		staff quarters			
			SNP 42501		Liwagu restaurant			
			SNP 42686		Pejabat Pemuliharaan			
42	Bignoniaceae	*Campsis radicans* (L.) Seem.	SNP 42326	KP headquarters complex	staff quarters	Boreal (Holarctic)	central and eastern USA	NA
43	Brassicaceae	*Cardamine flexuosa* With.	SNP 41998	KP headquarters complex	Pondok Silau-silau	Boreal (Holarctic)	Europe to Iran, Northwest Africa	L.1858978, Pahang, Malaysia (15 February 1987) Collector: Worthington RD
			SNP 42111		Kinabalu lodge			
			SNP 42346		staff quarters			
			SNP 42369		Liwagu restaurant			
			SNP 42444		Balsam café			
			SNP 42654		Pejabat Pemuliharaan			
44	Brassicaceae	*Nasturtium officinale* R.Br.	SNP 41586	Mesilau substation	Mesilau staff quarters SSL (L)	Boreal (Holarctic)	Europe to Central Asia and the Arabian Peninsula, Macaronesia, North and tropical Northeast Africa	L.1842387, Panar Laban, Sabah, Malaysia (05 August 1978) Collector: Smith JMB
			SNP 42933	Summit trail	Laban Rata			

Table 3 (continued)

No.	Family	Scientific name	Herbarium specimen No.	Study site	Location of plot	Origin (region of flora distribution)	Origin (country/continent)	Herbarium record
45	Cactaceae	*Epiphyllum oxypetalum* (DC.) Haw.	SNP 42178	KP headquarters complex	staff quarters	Boreal (Holarctic)	Central Mexico to Nicaragua	K000100069, Limbang, Sarawak, Malaysia (27 February 1990) Collector: Jenang
46	Commelinaceae	*Callisia fragrans* (Lindl.) Woodson	SNP 42455	KP headquarters complex	Balsam café	Neotropical	Mexico	NA
47	Commelinaceae	*Callisia repens* L.	SNP 42355	KP headquarters complex	staff quarters	Neotropical	southeastern Texas to tropical America	NA
48	Commelinaceae	*Tradescantia pallida* (Rose) D.R.Hunt	SNP 42342	KP headquarters complex	staff quarters	Neotropical	Mexico	NA
49	Commelinaceae	*Tradescantia zebrina* Bosse	SNP 42165	KP headquarters complex	Rock hostel	Neotropical	Mexico to Colombia	Negeri Sembilan, Malaysia (02 June 2015) Collector: L.H. Tnah & C.T. Lee
			SNP 42466		Liwagu resthouse			
			SNP 42605		Tibabar quarters			
50	Convolvulaceae	*Ipomoea batatas* (L.) Lam.	SNP 42200	KP headquarters complex	staff quarters	Neotropical	Mexico to Venezuela and Ecuador	L.2741413, Sarawak, Malaysia (05 December 1985) Collector: Paie I bin; Munting
51	Convolvulaceae	*Ipomoea tricolor* Cav.	SNP 41949	Mesilau substation	Mesilau SSL administration	Neotropical	Mexico	NA
			SNP 41977		Mesilau Genset			
			SNP 42033	KP headquarters complex	Hill lodge			
			SNP 42124		Kinabalu lodge			
			SNP 42398		Liwagu restaurant			
			SNP 42417		Balsam café			
			SNP 42570		Bilik Operasi			
			SNP 42622		Tibabar quarters			
			SNP 42646		Pejabat Pemuliharaan			
52	Crassulaceae	*Crassula ovata* Druce	SNP 42112	KP headquarters complex	Kinabalu lodge	South African (Capensic)	southeastern Mozambique to southeastern Cape Prov	NA
53	Crassulaceae	*Kalanchoe blossfeldiana* Poelln.	SNP 42314	KP headquarters complex	staff quarters	Palaeotropical	northeastern Madagascar	NA
			SNP 42496		Tibabar quarters			
54	Crassulaceae	*Kalanchoe daigremontiana* Raym.-Hamet & H.Perrier	SNP 42331	KP headquarters complex	staff quarters	Palaeotropical	southwestern Madagascar	NA
			SNP 42491		Tibabar quarters			
55	Cucurbitaceae	*Sicyos edulis* Jacq.	SNP 42179	KP headquarters complex	staff quarters	Neotropical	Mexico to Belize	Sarawak, Malaysia (09 March 1995) Collector: H.M. Christensen
			SNP 42438		Balsam café			
			SNP 42607		Tibabar quarters			

Table 3 (continued)

No.	Family	Scientific name	Herbarium specimen No.	Study site	Location of plot	Origin (region of flora distribution)	Origin (country/continent)	Herbarium record
56	Cupressaceae	*Juniperus virginiana* L.	SNP 42332	KP headquarters complex	staff quarters	Boreal (Holarctic)	southeastern Canada to central and eastern USA, Mexico (Coahuila)	NA
57	Euphorbiaceae	*Euphorbia pulcherrima* Willd. ex Klotzsch	SNP 42333	KP headquarters complex	staff quarters	Neotropical	Mexico to Guatemala	L.2222980, Kuala Lumpur, Malaysia (29 January 1969) Collector: Teo LE; Pachiappan G
			SNP 42387		Liwagu restaurant			
58	Euphorbiaceae	*Manihot esculenta* Crantz	SNP 42184	KP headquarters complex	staff quarters	Neotropical	western South America to Brazil	L.4291297, Malaysia (28 July 1908) Collector: -
			SNP 42430		Balsam café			
59	Fabaceae	*Arachis pintoi* Krapov. & W.C.Greg.	SNP 42060	KP headquarters complex	Hill lodge	Neotropical	central and eastern Brazil	NA
			SNP 42409		Balsam café			
			SNP 42536		Liwagu restaurant			
			SNP 42595		Bilik Operasi			
			SNP 42635		Tibabar quarters			
60	Fabaceae	*Mimosa pudica* L.	SNP 42341	KP headquarters complex	staff quarters	Neotropical	Mexico to tropical America	L.2041424, Sarawak, Malaysia (01 January 1929) Collector: Clemens J; Clemens MS
			SNP 42642		Pejabat Pemuliharaan			
61	Flagellariaceae	*Flagellaria indica* L.	SNP 42034	KP headquarters complex	Hill lodge	Palaeotropical	South Tanzania to Mozambique and West Pacific	L.1423550, Peninsular, Malaysia (01 January 1963) Collector: Herb Griffith
			SNP 42343		staff quarters			
			SNP 42427		Balsam café			
			SNP 42558		Kinabalu hall			
			SNP 42590		Bilik Operasi			
			SNP 42603		Tibabar quarters			
			SNP 42679		Pejabat Pemuliharaan			
62	Lamiaceae	*Mentha arvensis* L.	SNP 41568	Mesilau substation	Mesilau staff quarters TTS (RC & RM)	Boreal (Holarctic)	Europe to Kamchatka and Nepal	K000855795, Malaysia (19 th century) Collector: S.coll.
			SNP 42131	KP headquarters complex	Kinabalu lodge			
			SNP 42383		Liwagu restaurant			
			SNP 42440		Balsam café			

Table 3 (continued)

No.	Family	Scientific name	Herbarium specimen No.	Study site	Location of plot	Origin (region of flora distribution)	Origin (country/continent)	Herbarium record
63	Lythraceae	*Cuphea hyssopifolia* Kunth	SNP 42079	KP headquarters complex	Nepenthes lodge	Neotropical	Mexico to Central America	L.2478855, Pahang, Malaysia (0 October 1987) Collector: Worthington RD
			SNP 42126		Kinabalu lodge			
			SNP 42160		Rock hostel			
			SNP 42388		Liwagu restaurant			
			SNP 42494		Tibabar quarters			
			SNP 42544		Kinabalu hall			
64	Lythraceae	*Cuphea ignea* A.DC.	SNP 42301	KP headquarters complex	staff quarters	Neotropical	Mexico (Oaxaca, Chiapas)	Barcode 03040399, Pahang, Malaysia (09 November 1959) Collector: Abbe, L. B.; Abbe, E. C.; Tassim, K. B.; Omar, M. b.
65	Malvaceae	*Hibiscus rosa-sinensis* L.	SNP 42147	KP headquarters complex	Rock hostel	Palaeotropical	West Pacific	Selangor, Malaysia (25 January 1987) Collector: Richard D. Worthington
66	Malvaceae	*Hibiscus schizopetalus* (Dyer) Hook.f.	SNP 42371	KP headquarters complex	Liwagu restaurant	Palaeotropical	southeastern Kenya to eastern Tanzania	L.2358099, Sandakan, Sabah, Malaysia (16 March 1950) Collector: Kadir A
67	Malvaceae	*Hibiscus syriacus* L.	SNP 42323	KP headquarters complex	staff quarters	Palaeotropical	southern China, Taiwan	NA
68	Marantaceae	*Ctenanthe setosa* Eichl.	SNP 42145	KP headquarters complex	Rock hostel	Neotropical	eastern and southern Brazil	NA
			SNP 42499		Tibabar quarters			
69	Marantaceae	*Goeppertia zebrina* (Sims) Nees	SNP 42084	KP headquarters complex	Nepenthes lodge	Neotropical	Brazil (Bahia to Santa Catarina)	NA
			SNP 42668		Pejabat Pemuliharaan			
70	Melastomataceae	*Miconia crenata* (Vahl) Michelang.	SNP 42146	KP headquarters complex	Rock hostel	Neotropical	Mexico to tropical America	L.2537543, Sandakan, Sabah, Malaysia (14 June 1939) Collector: Kadir A; Enggoh L bin
			SNP 42329		staff quarters			
			SNP 42446		Balsam café			
			SNP 42469		Liwagu resthouse			
			SNP 42574		Bilik Operasi			
			SNP 42612		Tibabar quarters			

Table 3 (continued)

No.	Family	Scientific name	Herbarium specimen No.	Study site	Location of plot	Origin (region of flora distribution)	Origin (country/continent)	Herbarium record
71	Melastomataceae	*Pleroma urvilleanum* (DC.) P.J.F.Guim. & Michelang.	SNP 41579	Mesilau substation	Mesilau staff quarters SSL (W)	Neotropical	Brazil (São Paulo to Rio Grande do Sul)	L.3904090, Kinabalu National Park, Liwagu River Trail, Sabah, Malaysia (02 October 1995) Collector: Meyer Karsten
			SNP 42109	KP headquarters complex	Kinabalu lodge			
			SNP 42330		staff quarters			
			SNP 42419		Balsam café			
			SNP 42464		Liwagu resthouse			
			SNP 42549		Kinabalu hall			
			SNP 42589		Bilik Operasi			
			SNP 42663		Pejabat Pemuliharaan			
72	Molluginaceae	*Mollugo verticillata* L.	SNP 42944	Summit trail	Sayat-Sayat	Neotropical	America, Angola to Cape Prov	NA
73	Moraceae	*Ficus pumila* L.	SNP 41953	Mesilau substation	Mesilau SSL administration	Boreal (Holarctic)	central and southern China to temperate East Asia and mainland Southeast Asia	NA
			SNP 41978		Mesilau new administration office			
			SNP 42049	KP headquarters complex	Hill lodge			
			SNP 42524		Liwagu restaurant			
74	Moraceae	*Morus alba* L.	SNP 42076	KP headquarters complex	Nepenthes lodge	Boreal (Holarctic)	Central China	NA
			SNP 42302		staff quarters			
75	Oxalidaceae	*Oxalis triangularis* A.St.-Hil.	SNP 42174	KP headquarters complex	Rock hostel	Neotropical	Peru to Brazil and northern Argentina	NA
			SNP 42336		staff quarters			
			SNP 42530		Liwagu restaurant			
76	Pandanaceae	*Pandanus amaryllifolius* Roxb.	SNP 42181	KP headquarters complex	staff quarters	Palaeotropical	Maluku	NA
77	Passifloraceae	*Passiflora edulis* Sims	SNP 41930	Mesilau substation	Mesilau administration	Neotropical	Brazil to northeastern Argentina	L.2454292, Pahang, Malaysia (19 March 1973) Collector: Kasim M

Table 3 (continued)

No.	Family	Scientific name	Herbarium specimen No.	Study site	Location of plot	Origin (region of flora distribution)	Origin (country/continent)	Herbarium record
78	Plantaginaceae	*Plantago major* L.	SNP 41587	Mesilau substation	Mesilau staff quarters SSL (L)	Boreal (Holarctic)	temperate Eurasia to Arabian Peninsula, Macaronesia, North and South Africa	L.2843837, Port Dickson, N.Sembilan, Malaysia (20 January 1946) Collector: Monod de Froideville C
			SNP 41908		Mesilau Lows peak			
			SNP 41918		Mesilau Renanthera restaurant			
			SNP 41952		Mesilau SSL administration			
			SNP 41971		Mesilau Genset			
			SNP 41989	KP headquarters complex	Pondok Silau-silau			
			SNP 42001		Hill lodge			
			SNP 42090		Nepenthes lodge			
			SNP 42125		Kinabalu lodge			
			SNP 42159		Rock hostel			
			SNP 42327		staff quarters			
			SNP 42402		Bilik Operasi			
			SNP 42457		Balsam café			
			SNP 42485		Liwagu resthouse			
			SNP 42527		Liwagu restaurant			
			SNP 42637		Tibabar quarters			
			SNP 42904	Summit trail	Pondok Kandis			
			SNP 42918		Layang-layang			
			SNP 42936		Burlington			
79	Poaceae	*Axonopus compressus* (Sw.) P.Beauv.	SNP 42028	KP headquarters complex	Hill lodge	Neotropical	tropical and subtropical America	L.1219420, Penang, Malaysia (01 September 1921) Collector: Nur MD
			SNP 42506		Liwagu restaurant			
			SNP 42617		Tibabar l			
80	Poaceae	*Cenchrus purpureus* (Schumach.) Morrone	SNP 42170	KP headquarters complex	Rock hostel	Palaeotropical	Sahara to tropical Africa, Aldabra, Arabian Peninsula	BRA:IBT:SP:99269, Perak, Malaysia (04 August 1965) Collector: Samsuri
			SNP 42308		staff quarters			

Table 3 (continued)

No.	Family	Scientific name	Herbarium specimen No.	Study site	Location of plot	Origin (region of flora distribution)	Origin (country/continent)	Herbarium record
81	Poaceae	*Cymbopogon citratus* (DC.) Stapf	SNP 42032	KP headquarters complex	Hill lodge	Palaeotropical	South India, Sri Lanka	L.1235704, Sandakan, Sabah, Malaysia (01 September 1920) Collector: Ramos M.
			SNP 42148		Rock hostel			
			SNP 42307		staff quarters			
			SNP 42439		Balsam café			
			SNP 42608		Tibabar quarters			
82	Poaceae	*Cymbopogon nardus* (L.) Rendle	SNP 42130	KP headquarters complex	Kinabalu lodge	Palaeotropical	southern Sudan to South Africa and mainland Southeast Asia	L.1235438, Sandakan, Sabah, Malaysia (03 January 1950) Collector: Kadir A.
83	Poaceae	*Imperata cylindrica* (L.) Raeusch.	SNP 41563	Mesilau substation	Mesilau staff quarters TTS (RC & RM)	Palaeotropical	Mediterranean to Africa and Afghanistan	Barcode 04336929, Perak, Malaysia (27 November 1925) Collector: E. Seimund
84	Poaceae	*Panicum subalbidum* Kunth	SNP 42344	KP headquarters complex	staff quarters	Neotropical	tropical and South Africa, West Indian Ocean	NA
85	Poaceae	*Paspalum dilatatum* Poir.	SNP 42354	KP headquarters complex	staff quarters	Neotropical	southeastern and southern Brazil to South America	NA
86	Polygalaceae	*Polygala paniculata* L.	SNP 41564	Mesilau substation	Mesilau staff quarters TTS (RC & RM)	Neotropical	Mexico to tropical America	L.2172779, Penang, Malaysia (15 November 1950) Collector: Sinclair J
			SNP 41574		Mesilau staff quarters SSL (W)			
			SNP 41910		Mesilau Lows peak			
			SNP 42005	KP headquarters complex	Hill lodge			
			SNP 42100		Nepenthes lodge			
			SNP 42110		Kinabalu lodge			
			SNP 42356		staff quarters			
			SNP 42381		Liwagu restaurant			
			SNP 42425		Balsam café			
			SNP 42546		Kinabalu hall			
			SNP 42566		Bilik Operasi			
			SNP 42609		Tibabar quarters			
			SNP 42660		Pejabat Pemuliharaan			
			SNP 42906	Summit trail	Kemburongoh Telekom			

Table 3 (continued)

No.	Family	Scientific name	Herbarium specimen No.	Study site	Location of plot	Origin (region of flora distribution)	Origin (country/continent)	Herbarium record
87	Portulacaceae	*Portulaca oleracea* L.	SNP 42426	KP headquarters complex	Balsam café	Palaeotropical	Macaronesia, tropical Africa, Mediterranean to Pakistan and Arabian Peninsula	L.1687078, Cameron Highlands, Pahang, Malaysia (23 April 1937) Collector: Nur MD
			SNP 42498		Tibabar quarters			
88	Primulaceae	*Lysimachia congestiflora* Hemsl.	SNP 42324	KP headquarters complex	staff quarters	Boreal (Holarctic)	Nepal to China and mainland southeast Asia, Taiwan	NA
89	Rosaceae	*Fragaria ananassa* (Duchesne ex Weston)	SNP 42334	KP headquarters complex	staff quarters	Boreal (Holarctic)	British Columbia, California, Oregon, Washington	NA
90	Rosaceae	*Rosa pendulina* L.	SNP 42026	KP headquarters complex	Hill lodge	Palaeotropical	Europe to Kazakhstan	NA
			SNP 42127		Kinabalu lodge			
			SNP 42156		Rock hostel			
			SNP 42303		staff quarters			
			SNP 42414		Balsam café			
			SNP 42533		Liwagu restaurant			
			SNP 42639		Tibabar quarters			
91	Solanaceae	*Brugmansia suaveolens* (Willd.) Sweet	SNP 42404	KP headquarters complex	Balsam café	Neotropical	Brazil (southern Bahia to northern Rio Grande do Sul)	NA
92	Solanaceae	*Cestrum nocturnum* L.	SNP 42054	KP headquarters complex	Hill lodge	Neotropical	Mexico to Venezuela	V- 036755, Pulau Pinang, Malaysia (08 December 1984) Collector: Olof Ryding
			SNP 42117		Kinabalu lodge			
			SNP 42153		Rock hostel			
			SNP 42680		Pejabat Pemuliharaan			
93	Solanaceae	*Physalis minima* L.	SNP 41926	Mesilau substation	Mesilau Renanthera restaurant	Neotropical	tropical and subtropical America	E00686566, Malaysia (31 October 1913) Collector: -
			SNP 41937		Mesilau administration			
			SNP 41940		Mesilau SSL administration			
			SNP 41964		Mesilau Genset			
			SNP 41986		Mesilau new administration office			
			SNP 42483	KP headquarters complex	Liwagu resthouse			
			SNP 42585		Bilik Operasi			
			SNP 42645		Pejabat Pemuliharaan			
94	Solanaceae	*Solanum betaceum* Cav.	SNP 41591	Mesilau substation	Mesilau Witti range 3–4	Neotropical	tropical South America	L.2864399, Kundasang, Sabah, Malaysia (21 April 1984) Collector: Beaman JH; Beaman RS; Beaman TE; Decker P

Table 3 (continued)

No.	Family	Scientific name	Herbarium specimen No.	Study site	Location of plot	Origin (region of flora distribution)	Origin (country/continent)	Herbarium record
95	Verbenaceae	*Duranta erecta* L.	SNP 41585	Mesilau substation	Mesilau staff quarters SSL (L)	Boreal (Holarctic)	southern Florida to the Caribbean, Mexico to North America	Selangor, Malaysia (20 January 1987) Collector: Richard D. Worthington
			SNP 41915		Mesilau Renanthera restaurant			
			SNP 41945		Mesilau SSL administration			
			SNP 42315	KP headquarters complex	staff quarters			
96	Verbenaceae	*Lantana camara* L.	SNP 42121	KP headquarters complex	Kinabalu lodge	Neotropical	Mexico to tropical America	L.2766376, Malaysia (21 April 1885) Collector: Suringar, WFR
			SNP 42176		staff quarters			
			SNP 42625		Tibabar quarters			
97	Verbenaceae	*Stachytarpheta jamaicensis* (L.) Vahl	SNP 42339	KP headquarters complex	staff quarters	Neotropical	southeastern USA to tropical America	L.2773155, Port Dickson, Negeri Sembilan, Malaysia (24 January 1946) Collector: Monod de Froideville C
98	Zingiberaceae	*Curcuma longa* L.	SNP 42183	KP headquarters complex	staff quarters	Palaeotropical	southwestern India	NA

Supplementary Information

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