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Alien Flora on Weizhou Island, Northern South China Sea: Inventory and Invasion Risk Assessment

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Abstract

Islands subjected to anthropogenic disturbance are highly susceptible to alien plant invasions. However, the alien floral diversity of China's islands has been insufficiently studied, hindering its control. Weizhou Island (northern South China Sea) has experienced long-term human exploitation. We inventorized its alien, naturalized, and invasive vascular plants (based on herbarium specimen data for 2018–2024 and surveys of 112 plots); analyzed species composition, origins, life forms, and habitats; and conducted an invasive species risk assessment. This identified 203 aliens, including infraspecific and hybrid taxa, 129 (63.5%) naturalized and 71 (55.0% of the naturalized species) invasive. The aliens were dominated by the Fabaceae, Asteraceae, and Euphorbiaceae, particularly genera such as *Euphorbia*, *Senna*, and *Portulaca*, originating primarily in North America, Oceania, and Africa. Perennial herbs were the most common lifeform, followed by annual herbs and shrubs. Invasion hotspots were primarily abandoned farmland, roadsides, and agricultural lands. Using the Analytic Hierarchy Process, we classified the 71 invasive species as representing high-risk, moderate-risk, and low-risk (20, 16, and 35 species, respectively). *Bidens pilosa*, *Ageratum conyzoides*, *Opuntia dillenii*, and *Leucaena leucocephala* pose severe threats to the island ecosystem. This first complete inventory of the alien flora on Weizhou Island offers critical insight into the management of invasive alien plants in island ecosystems.

Keywords: invasive alien plant; naturalized species; risk assessment; inventory; Weizhou Island

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1. Introduction

A hallmark of the Anthropocene is the escalating threat of human-mediated biological invasions to global biodiversity, economies, and public health [1–3]. The latest assessment of invasive alien species has revealed that over 37,000 introduced species have established populations worldwide, including more than 3500 invasive species [4]. Globally, at least 13,939 plant species (representing 3.9% of the extant vascular flora) have naturalized beyond their native ranges [5,6]; of these, approximately 2500 are considered invasive [7]. Although most introduced species fail to establish self-sustaining populations in the wild, a significant proportion successfully naturalize as their populations grow [8]. Detailed inventories of occurrence records are essential for managing problematic alien species [2,9].

Invasive species constitute a subset of naturalized species, which are in turn a subset of aliens [10]. Elucidating the relationships among these three groups is critical for pre-

dicting and preventing biological invasion. Naturalization occurs when intentionally or unintentionally introduced aliens overcome abiotic and biotic barriers to their survival and reproduction [11]. Naturalized plants may become invasive only when they produce sufficiently reproductive offspring in their new habitats [1]. Compiling complete inventories of naturalized species for specific countries or regions, along with comparative studies of regional naturalized flora, is an effective way to elucidate plant invasion patterns and a primary step in developing invasive species management strategies [5,9]. Over the past decade, the global distribution data of alien, naturalized, and invasive species across various taxonomic groups has been progressively refined [5,12–15]. For instance, Spampinato et al. [16] documented 382 alien plant species in Calabria (Southern Italy), including 127 naturalized and 48 invasive species. Iran hosts 311 alien vascular plants, of which 167 are naturalized and 13 are invasive [17], whereas Pakistan has 400 alien taxa, of which 117 are naturalized and 103 are invasive [18]. Complete inventories of alien plants are essential for addressing key questions in invasion biology and conducting risk assessment [15]. Comprehensive documentation of alien, naturalized, and invasive plants at national or regional scales provides vital data for comparative studies of alien flora, yielding novel insights into the global patterns and dynamics of plant invasions.

Islands serve as ideal natural laboratories for studying biological evolution, ecology, and climate change. Their unique environmental characteristics foster distinct biotic assemblages, while presenting substantial challenges to survival [19,20]. Global urbanization efforts and expanding tourism and trade in island territories [21], coupled with heightened vulnerability to typhoons, storm surges, and other natural disasters, have compromised the limited self-regulatory capacity of island ecosystems. This has precipitated environmental degradation and the loss of biodiversity [22]. The inherent fragility of island ecosystems renders them particularly susceptible to native species displacement and ecosystem service deterioration following alien species introductions [19,20,23]. These perturbations often result in the phenomenon known as "biotic homogenization", which involves taxonomic and functional simplification [2,6,24]. Islands experience disproportionately worse impacts from biological invasions than mainland areas [25–28]. Numerous alien species, introduced intentionally or accidentally, have naturalized on islands, with some becoming invasive. These invaders have driven extensive extinctions of native species, while fundamentally altering trophic interactions and insular biodiversity patterns [29]. Despite these threats, recent research has focused predominantly on distribution of alien species in mainland areas [10,16–18], with comparatively limited attention given to heavily developed island ecosystems [19,20]. Accurate monitoring, documentation, and reporting of the alien species taxonomy, abundance, and traits on islands are critical. Such efforts facilitate the development by conservation agencies and governmental bodies of effective management strategies, encompassing habitat restoration, invasive species eradication, and ex situ conservation initiatives, that aim to mitigate biodiversity loss in island ecosystems [28].

China ranks among the countries with flora most severely affected by invasive alien plants (IAPs) [30]. Current floristic inventories document 14,710 alien plant species nationwide, including 984 naturalized and 391 invasive taxa [31]. However, while plant invasions have been well studied for mainland China, they remain poorly examined for its island ecosystems. Luo et al. [32] comprehensively surveyed IAPs on Pingtan Island (Fujian Province, China), identifying 104 invasive species and developing a risk assessment framework for island-specific invasion threats. Xie et al. [33] recorded 142 IAPs (spanning 102 genera and 38 families) across 77 islands of Fujian Province, China, identifying the proportions of built-up and agricultural areas, island size, and maximum elevation as the primary drivers of invasive species richness and growth patterns. Despite China's national invasive species census [30], island invasion data remain limited in

terms of detail and comprehensiveness. Although some studies have focused on IAPs on islands [19,32,33], broader alien and naturalized species pools on islands have rarely been investigated. This knowledge gap hinders the early detection of potential invaders and delays targeted management.

Guangxi, in southern China, is among the provinces most severely affected by biological invasions [34]. The number of IAPs in Guangxi increased from 74 in 2008 [35] to 180 in 2019 [36], with these species causing significant harm to local ecosystems. Weizhou Island, in the northern South China Sea, is the largest island in Guangxi [37]. Owing to its unique geographical location and natural landscape, the island has become a representative area for coastal tourism development and socioeconomic transformation in Guangxi Province [38]. Its geographical and climatic conditions, combined with a thriving tourism industry, and highly disturbed habitats create favorable conditions for the introduction, establishment, and spread of alien plants, posing significant risks of plant invasion. However, the composition of alien, naturalized, and invasive plants on Weizhou Island remains poorly understood, hindering the development of effective prevention and control measures against invasive species on this island.

To address this gap, we comprehensively inventorized the alien, naturalized, and invasive vascular plants on Weizhou Island, using plant specimen data and survey data for 112 plots. We aimed to examine the taxonomic composition, origins, life forms, and habitat preferences of its alien flora, to conduct an IAP risk assessment and to recommended management strategies for IAPs on islands. These findings provide new insights for the prevention and management of IAPs on Weizhou Island, thereby promoting the healthy development of the island ecosystem.

2. Materials and Methods

2.1. Study Area

Weizhou Island (20°54′–21°10′ N, 109°00′–109°15′ E; Figure 1) falls administratively within Guangxi Province. With its nearest point 40 km from the mainland, the island covers a total area of 24.74 km^2, reaching a maximum elevation of 79 m a.s.l. [37,39]. The island has a South Asian tropical maritime climate, with frequent typhoons and torrential rains during summer and autumn. This island has an average annual temperature of 22.6 °C, with January being the coldest month (15.3 °C) and July the warmest (28.9 °C). With an annual precipitation of 1380.2 mm and relative humidity averaging 82.0%, it ranks as one of Guangxi's warmest and wettest regions [39]. As China's youngest volcanic island, volcanic rock formations constitute >95.0% of its lithology. The soils are predominantly volcanic in origin, with basalt-derived lateritic red earth and sandy loam as the primary parent materials, and are characterized by high concentrations of nitrogen, phosphorus, and potassium [40]. In the northeast, the island is mostly cultivated, while orchards dominate in the central and southern areas. Forests (consisting mainly *Casuarina equisetifolia*, *Leucaena leucocephala*, and *Acacia confusa* plantations) are distributed primarily along the northern and southern coastal zones [39]. The island has a permanent population of 15,000, with densely populated areas clustered in the western sector. As a renowned Chinese 5A-class national tourist attraction, Weizhou Island received approximately 2.1353 million visitors in 2023 [38].

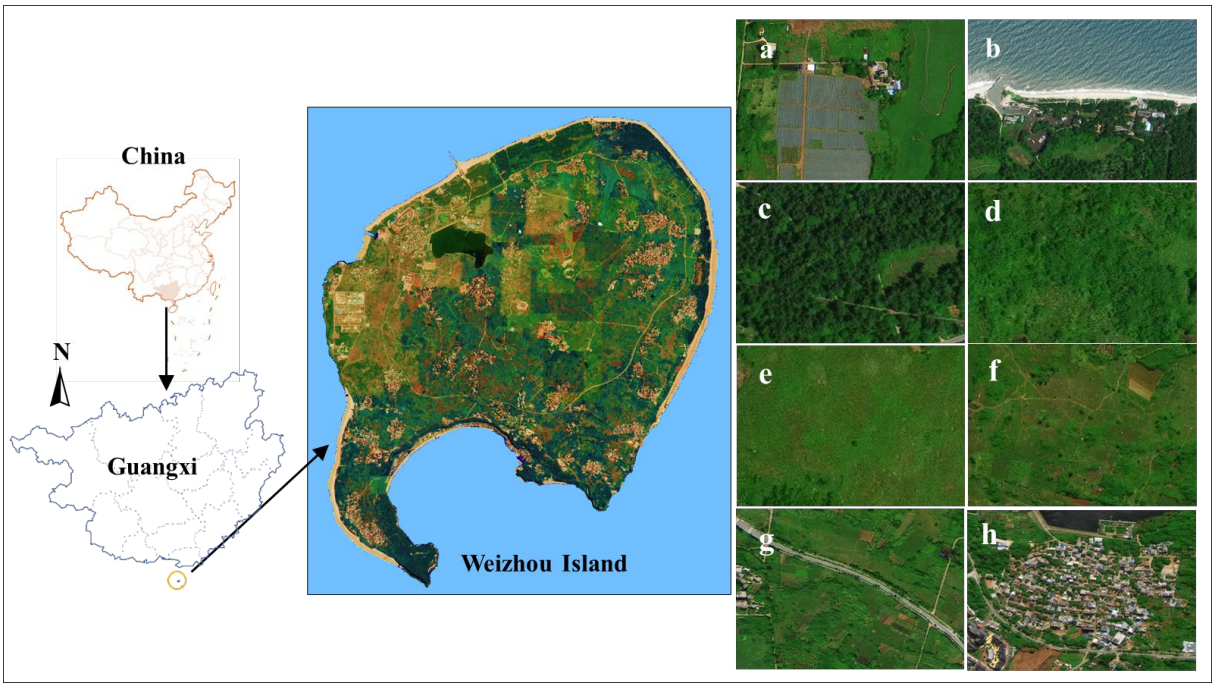


Figure 1. Location and eight habitat types of Weizhou Island in the northern South China Sea. (**a**), agricultural land; (**b**), coastal zone, (**c**), plantation; (**d**), shrubland; (**e**), grassland; (**f**), abandoned farmland; (**g**), roadside; (**h**), residential area.

2.2. Field Survey

We conducted an extensive plant specimen collection [16] on Weizhou Island during 12 field surveys across different seasons from 2018 to 2024. Based on the island's land-use types and vegetation conditions, and with reference to habitat classification method used for other island [32], we classified its habitats into eight categories: agricultural land, coastal zones, plantations, shrubland, grassland, abandoned farmland, roadsides, and residential areas. Across these habitat types, we collected 2352 plant specimens and deposited them in the herbarium of Nanning Normal University. Each specimen was annotated with taxonomic information, habitat type, and collection location [16]. Additionally, from July to August 2023–2024, we conducted plot surveys of the eight habitat types using plot sizes of 2 m × 2 m and 5 m × 5 m. In total, 46 survey sites were selected (four to nine sites per habitat type), with two to four plots at each site, resulting in 112 plots. Within each plot, we recorded the taxonomic composition of all plant species, the numbers of individuals, average height, coverage, abundance, and habitat type [32].

2.3. Identification as Alien, Naturalized, or Invasive

In studies of alien species, the definitions of "non-native," "non-indigenous," "naturalized," and "invasive" are often conflated [41,42], leading to discrepancies in the reported abundances and impact ranges of aliens [43]. To better characterize the composition of plants on Weizhou Island, we adopted the following definitions: "alien" refers to species introduced beyond their natural native distribution range [44]. "Naturalized" (or "established"), a subset of "alien," refers to plants that can form self-sustaining populations and complete multiple life cycles without direct human intervention [45]; and "invasive," a subset of "naturalized," refers to plants that exhibit high reproductive output and can spread over considerable distances [45]. Based on the collected specimen records and plot survey data, and referring to Lin et al. [31] and Hao and Ma [46], we inventorized the alien, naturalized, and invasive vascular plants on Weizhou Island. The native origins of the species were identified, following Lin et al. [31], as North America, Africa, South

America, Asia, Europe, or Oceania. Life forms (tree, shrub, woody vine, herbaceous vine, annual herb, perennial herb, and bamboo) were determined based on field observations and using the approach of Lin et al. [31]. The habitat preferences of the invasive species were identified based on the habitat characteristics of the specimen collection sites and on plot locations.

2.4. Data Analysis

We employed Sankey diagrams to visualize the top ten families and genera, along with seven life form types, based on their species contributions to the alien flora. Additionally, chord diagram was used to display the six phytogeographic origins of the alien flora. All figures were generated using Origin 2023 software (OriginLab, Northampton, MA, USA).

Invasion Risk Assessment, a tool for proactively identifying high-risk plants with potential ecological or economic impacts, forms the foundation for alien species risk management [47]. The risk assessment evaluates invasive species across multiple dimensions, including invasion history, environmental adaptability, growth traits, biological characteristics, dispersal mechanisms and capacity, potential hazards and impacts, and difficulties in containment and quarantine. Here, we adopted the Analytic Hierarchy Process-based framework, a widely used weighting-based decision-making method that hierarchically quantifies criteria and combines qualitative and quantitative analyses, to assess alien plant invasion risk [48]. The final risk levels were classified using composite scores (p-values, maximum 100) derived from a hierarchical evaluation system comprising seven primary indicators, 17 secondary indicators, and 55 tertiary indicators [32,48,49]. The total P value reflects the sum of the weighted indicator scores and correlates positively with risk magnitude. This early warning system categorizes risks into three tiers: high-risk ($p \geq 40$), requiring enhanced control measures and strict quarantine protocols; moderate-risk ($33 \leq p < 40$), requiring preventive intervention; and low-risk ($p < 33$), requiring monitoring but no immediate action [48].

3. Results

3.1. Floral Composition

We identified 203 alien vascular plant species (in 55 families and 162 genera) on Weizhou Island, including 129 naturalized species (41 families and 100 genera) and 71 invasive species (48 families and 55 genera) (Appendix A Table A1). Asteraceae, Fabaceae, and Euphorbiaceae exhibited dominated among the alien, naturalized, and invasive species (Figure 2a). Monotypic families (i.e., those containing only one species) accounted for 22, 18, and 14 families in the alien, naturalized, and invasive species pools, respectively (Appendix A Table A1). At the genus level, *Euphorbia*, *Senna*, and *Amaranthus* were the most species-rich genera across all categories (Figure 2b), whereas monotypic genera numbered 137, 83, and 46 for alien, naturalized, and invasive species, respectively (Appendix A Table A1). Among the alien plants, naturalization rates reached 100.0% in Asteraceae (18 species), 100.0% in Amaranthaceae (eight species), 90.0% in Solanaceae (10 species), and 73.0% in Fabaceae (18 species), whereas their respective invasion rates were 88.9%, 75.0%, 60.0%, and 44.0%. All three alien species of *Amaranthus* were found to be invasive. In contrast, naturalization rates of 87.5%, 100.0%, and 100.0% were observed for *Euphorbia* (eight species), *Senna* (four species), and *Solanum* (four species), respectively, with invasion rates of 75.0%, 75.0%, and 60.0%, respectively.

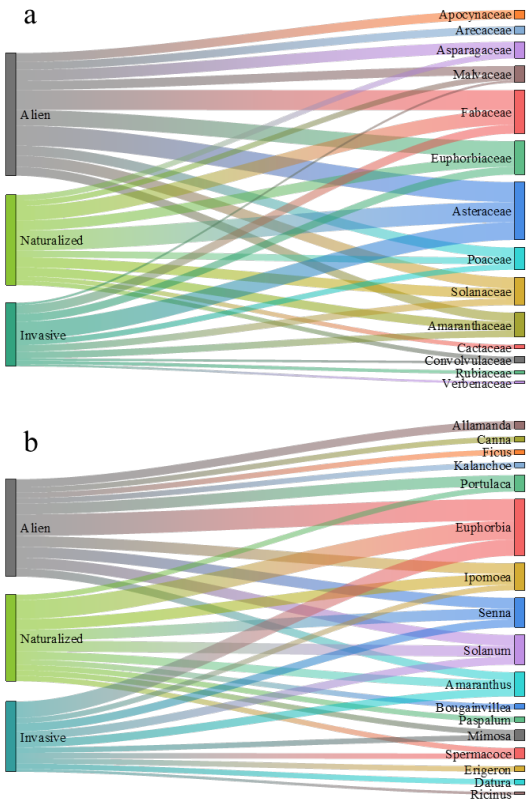


Figure 2. Top ten families (**a**) and genera (**b**) in terms of number of species contributing to the alien flora on Weizhou Island.

3.2. Origin

The alien plants on Weizhou Island originated primarily from North America (107 species), Africa (34), Asia (34), South America (13), Oceania (13), and Europe (2) (Figure 3, Appendix A Table A1). Among the naturalized plants, 81 species were native to North America, 19 to Africa, 16 to Asia, 10 to South America, and three to Oceania, with no European-origin naturalizations (Figure 3, Appendix A Table A1). The invasive species were predominantly from North America (54 species), contrasting sharply with lower counts from Africa (7), South America (6), Asia (3), and Oceania (1) (Figure 3, Appendix A Table A1). Notably, 50.5% of the North American and 46.2% of the South American alien plants identified were invasive (Figure 3).

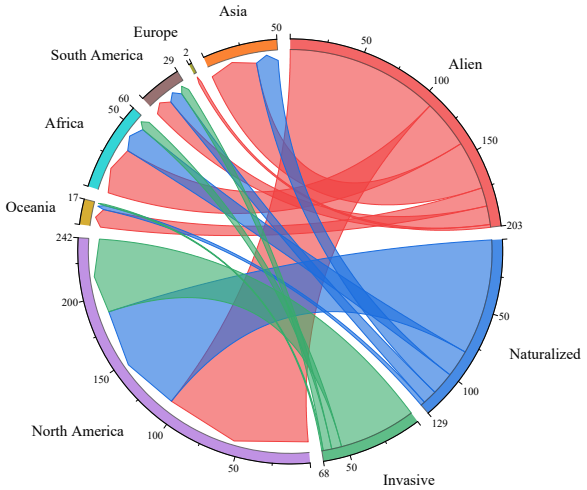


Figure 3. Phytogeographic origins of the alien flora on Weizhou Island.

3.3. Life Form

The alien flora of Weizhou Island was dominated by perennial herbs (59 species), followed by shrubs (46), trees (37), annual herbs (33), and herbaceous vines (21), with only six woody vine and one bamboo species recorded (Figure 4, Appendix A Table A1). Among the naturalized plants, perennial herbs (46 species), annual herbs (30), and shrubs (29) were the most prevalent, whereas herbaceous vines (11), trees (10), and woody vines (3) were less common, and no bamboo species were naturalized (Figure 4, Appendix A Table A1). Invasive species were similarly dominated by perennial herbs (31 species) and annual herbs (22), with 12 shrub species but only four herbaceous vines, two trees, and no woody vines being invasive (Figure 4, Appendix A Table A1). Of the aliens, 66.7% of the annual herbs and 52.5% of the perennial herbs were invasive, compared with 21.8% of the shrubs, 19.0% of the herbaceous vines, and 5.4% of the trees (Figure 4).

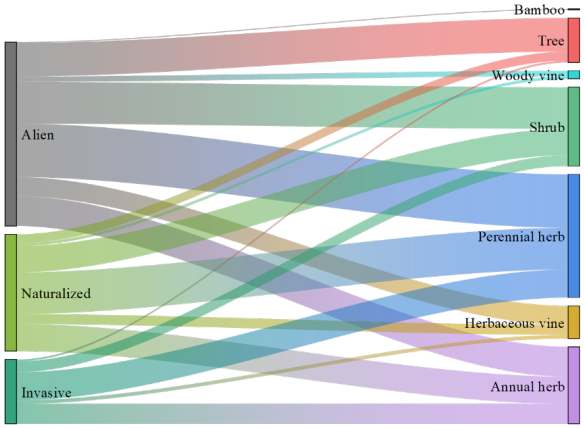


Figure 4. Life forms of the alien flora on Weizhou Island.

3.4. Habitat

All eight habitat types on Weizhou Island harbored a substantial number of alien plant species (Figure 5). Alien species were predominantly found on agricultural land (118 species), abandoned farmland (95), roadsides (76), and plantations (63). Notably, alien species exhibited higher naturalization rates on abandoned farmland (69 species, 72.6%), roadsides (55, 72.4%), and grassland (37, 69.8%) and lower rates on agricultural land (38.1%) and in coastal zones (46.1%). Invasive species were most prevalent in abandoned farmland (51 species), roadsides (42), and agricultural lands (31) and less common in shrublands (12) and coastal zones (8). On roadsides, abandoned farmland, and grassland, 55.3%, 53.7%, and 47.2% of the aliens were invasive (Figure 5).

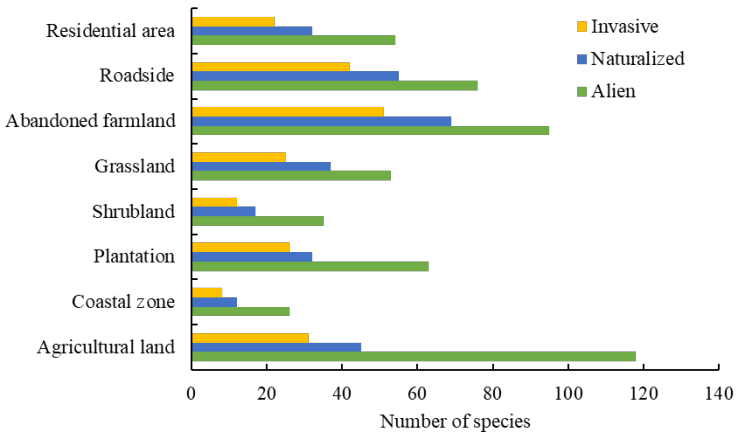


Figure 5. Alien flora species distribution by habitats for Weizhou Island.

3.5. Risk Assessment

Based on risk assessment, 20 (28.2%) of the 71 IAPs were classified as high-risk ($p \geq 40$) (Figure 6, Appendix A Table A1). These included *Bidens pilosa* (Figure 7a), *Ageratum conyzoides* (Figure 7b), *Opuntia dillenii* (Figure 7c), and *Leucaena leucocephala* (Figure 7d). Sixteen species (22.5%), including *Parthenium hysterophorus* (Figure 7e), *Richardia scabra* (Figure 7f), *Datura stramonium* (Figure 7g), and *Mimosa pudica* (Figure 7h), were categorized as moderate-risk ($33 \leq p < 40$) (Figure 6, Appendix A Table A1). The remaining 35 species (49.3%), including *Mirabilis jalapa*, *Pilea microphylla*, *Gomphrena celosioides*, and *Hydrocotyle verticillata*, were classified as low-risk ($p < 33$) (Figure 6, Appendix A Table A1).

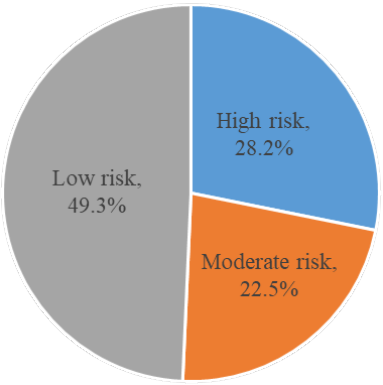


Figure 6. Invasion Risk Assessment levels of the invasive alien plants on Weizhou Island, with species numbers.

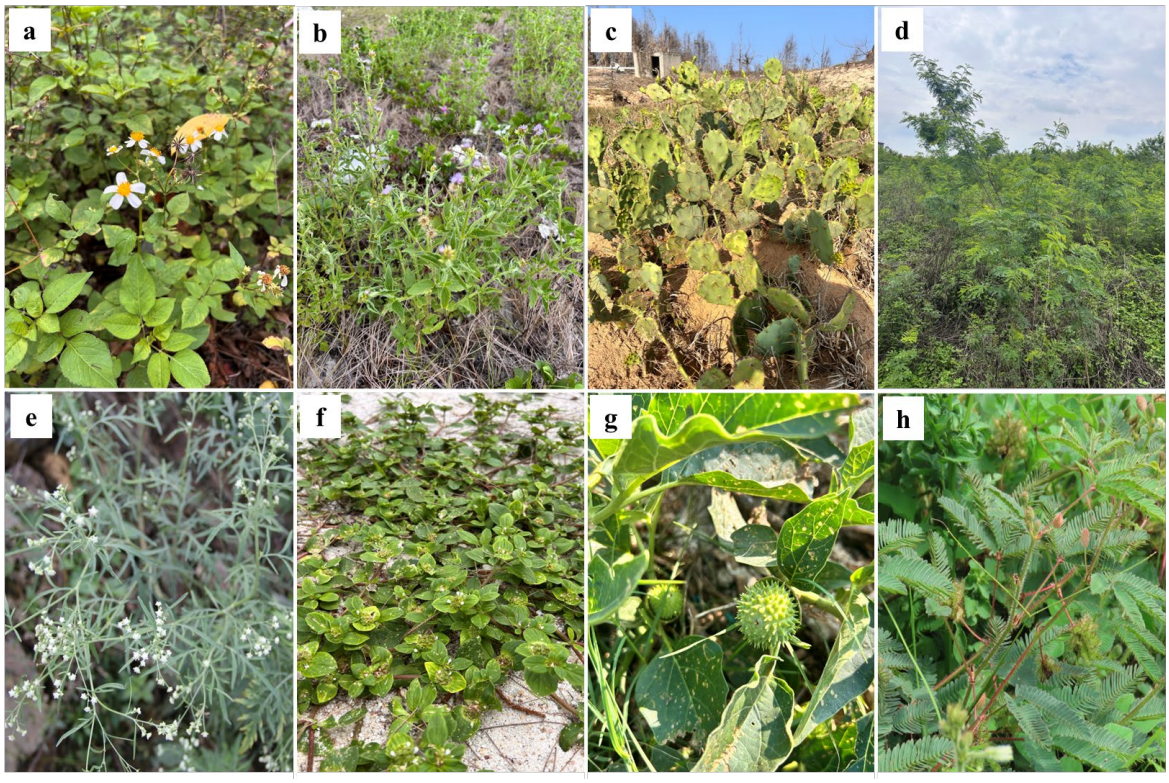


Figure 7. Photographs of selected invasive alien plants on Weizhou Island. (**a**), Bidens Pilosa; (**b**), Ageratum conyzoides; (**c**), Opuntia dillenii; (**d**), Leucaena leucocephala; (**e**), Parthenium hysterophorus; (**f**), Richardia scabra; (**g**), Datura stramonium; (**h**), Mimosa pudica.

4. Discussion

4.1. Status of Alien Flora on Weizhou Island

This study identified 203 alien vascular plant species (in 55 families and 162 genera), including 129 naturalized species (41 families and 100 genera) and 71 invasive species (48 families and 55 genera); 63.5% of the alien species were naturalized, and 55.0% of the naturalized species were invasive. Recent surveys have indicated that Weizhou Island hosts 608 vascular plant species (126 families and 427 genera) [50]; alien plants therefore constitute 33.4% of the total flora, whereas naturalized and invasive species account for 21.2% and 11.7%, respectively. Notably, although Weizhou Island (24.74 km^2) represents only 0.01% of Guangxi's land area (237,600 km^2), it harbors 39.4% of its 180 documented IAPs [36]. While Pingtan Island (324.13 km^2 in Fujian province) has 104 invasive species, Weizhou has 68.3% as many [32], despite covering only 7.6% of its area, with high levels of species similarity between the two islands. Invasive species typically have a magnified impact on small islands, owing to their smaller populations of native species [26–28]. Our findings provide evidence that small islands such as Weizhou Island face worse plant invasions than mainland areas or larger islands such as Pingtan, which is consistent with previous findings [20,23,27]. The high proportions of alien, naturalized, and invasive vascular plants on Weizhou Island suggest that it has experienced acute biological invasions, potentially leading to ecosystem damage. The urgent implementation of invasive species management strategies is imperative for mitigating further biodiversity loss in small island ecosystems.

Among the alien, naturalized, and invasive plants on Weizhou Island, Asteraceae, Fabaceae, and Euphorbiaceae exhibited the highest species richness, with these families exhibiting high rates of invasiveness. The genera with the most invasive species were *Euphorbia*, *Senna*, *Amaranthus*, and *Solanum*, revealing that Weizhou Island shares compositional similarities in terms of invasive plant families and genera with mainland China [10,31,51] and other islands [19,32]. Notably, Asteraceae, Fabaceae, and Poaceae, among the world's largest plant families, are major contributors to global [5] and regional [16,31] alien flora. Their widespread introduction is closely tied to their economic value; approximately 50.0% of alien Asteraceae species in China were introduced as ornamentals and 42.0% of Poaceae species as forage crops, whereas Fabaceae species were introduced primarily as ornamentals or fodder [51]. Reproductive capacity and dispersal efficiency are critical determinants of invasion success [34]. Alien plants must produce and disseminate sufficient numbers of propagules in novel environments to establish invasive populations [52]. Consequently, the dominance of Asteraceae, Fabaceae, and Euphorbiaceae is linked to their superior long-distance dispersal capacity, establishment success, colonization ability, and environmental adaptability [53].

The majority of the alien plants on Weizhou Island originated from North America, Africa, and Asia, with naturalized and invasive species exhibiting the same pattern. The geographical origins of naturalized species may influence their invasiveness in newly introduced regions [54]. The origins of the alien plants in this study are consistent with the reported origins of non-native flora in China and other islands [31,32]. IAPs from similar climatic zones as the invaded island exhibit stronger adaptability and higher rates of colonization and dispersal [18]. Studies suggest that most of its invasive species on an island originate from within the same climatic zone as the island [19,20,23]. Within Weizhou Island's alien flora, species from North America dominate, primarily because their naturalization success is enhanced by climatic and biogeographic similarities. China and North America share numerous analogous environments and associated biomes, which may increase their mutual susceptibility to immigrant species. The surge in trade between China and the Americas over recent decades has likely facilitated a substantial increase in

the introduction of plant propagules from North America [34,55]. The high proportions of alien, naturalized, and invasive plants from Africa and Asia on Weizhou Island are similarly related to climatic conditions, trade, and tourism.

Perennial herbs dominate the alien flora of Weizhou Island, with 66.7% of perennial and 52.5% of annual herbaceous alien species becoming invasive, while shrubs and lianas exhibit lower invasion rates (e.g., 5.4% for trees). This is consistent with the global tendency for herbaceous taxa to dominate among alien, naturalized, and invasive plant assemblages [5]. Similar herbaceous dominance characterizes the alien flora of both China and Guangxi [31,36]. The perennial life history, often associated with vegetative reproduction and clonal growth, may contribute significantly to invasion success [56]. Herbaceous aliens exhibit better competitive ability and greater phenotypic plasticity than most native species, owing to their rapid reproduction, high seed output, efficient dispersal of small propagules, and strong invasive capacity [57]. The limited occurrence of naturalized and invasive woody plants (trees and shrubs) likely relates to their deliberate introduction for horticulture, timber production, and coastal erosion control, with subsequent escape from cultivation. However, the invasive tree species *Leucaena leucocephala* has become dominant in some plant communities on Weizhou Island, causing significant ecological impacts.

All eight habitat types on Weizhou Island experienced varying degrees of alien plant invasion, with high species richness observed on abandoned farmland, roadsides, and agricultural land. Anthropogenically modified habitats typically exhibit elevated invasion levels owing to heightened human disturbance and propagule pressure [58]. Compared with mainland areas, island ecosystems exhibit higher rates of habitat occupancy by alien plants and face greater threats from invasive species [19,32]. Alien species dominate on abandoned farmland, roadsides, and agricultural land as the frequent human disturbance associated with these habitats creates many opportunities for colonization [59]. Roads serve dual roles as both reservoirs for invasive plant propagules and dispersal corridors [60]. The development of infrastructure, including roads, ports, urban areas, villages, and modified coastal zones, amplifies propagule pressure while enhancing the dispersal efficiency and colonization potential of alien plants. The diverse habitat types of Weizhou Island may accommodate large numbers of individuals of IAPs, facilitating their dispersal and establishment. This highlights the importance of implementing management strategies to prevent the spread of invasive species and their negative effects in these vulnerable habitats.

4.2. Risk Assessment of IAPs on Weizhou Island

We classified the 71 IAPs as high-risk (20 species, 28.2%), moderate-risk (16 species, 22.5%), and low-risk (35 species, 49.3%). The high-risk alien species have adapted to most of the adverse conditions on Weizhou Island and are extremely common there. For instance, IAPs such as *Bidens pilosa*, *Ageratum conyzoides*, *Erigeron canadensis*, *Crassocephalum crepidioides*, *Symphyotrichum subulatum*, *Praxelis clematidea*, *Lantana camara*, *Spermacoce alata*, and *Ipomoea cairica* dominate in many of the plant communities in and around the island's villages, exhibiting high population densities and coverage rates. Six species—*Lantana camara*, *Mikania micrantha*, *Sphagneticola trilobata*, *Eichhornia crassipes*, *Leucaena leucocephala*, and *Opuntia stricta*—are among the 100 most invasive alien species globally, according to the IUCN [61]. *Leucaena leucocephala* and *Opuntia stricta* have become dominant in the coastal vegetation (Figure 7c,d), displacing the native coastal plants and altering the natural landscape. Originally introduced as fuelwood, *Leucaena leucocephala* has exhibited rapid growth and strong regenerative capacity over the past decade, spreading across most of the island as the demand for firewood has declined. The recently introduced *Mikania micrantha* exhibits extreme invasiveness and rapid dispersal and has established

populations at multiple sites on the island. Moderate-risk IAPs, including *Parthenium hysterophorus*, *Richardia scabra*, *Datura stramonium*, and *Mimosa pudica*, have caused localized damage. Introduced ornamental species such as *Mirabilis jalapa*, *Pilea microphylla*, and *Hydrocotyle verticillata* currently pose a low invasion risk but require monitoring owing to their documented impacts in mainland China [46]. The dynamics of their distribution on the island thus require special attention.

Many of these IAPs were introduced to the island for cultivation. Subsequent neglect following their intentional introduction has enabled them to occupy substantial habitats, outcompeting the native flora and impeding its survival and growth [29]. IAPs have severely affected the island's ecosystems, causing ecological degradation and biodiversity loss, and further unchecked invasion may lead to the replacement and local extinction of indigenous species. Species with documented histories of invasion on oceanic islands are more likely to invade other islands than naturalized alien species [19,20]. Consequently, the naturalized and invasive species identified here likely pose high risks of naturalization or invasion for other South China Sea islands.

4.3. Invasion Mechanisms of Alien Species on Weizhou Island

The exceptionally high richness of naturalized and invasive plants on islands is due to biogeographic (e.g., smaller regional species pools and unsaturated island communities), ecological (e.g., competitively weaker native species), and socioeconomic (e.g., tourism development, farmland abandonment, and coastal anthropogenic activity) factors [19,20,62]. Disturbance intensity (i.e., habitat quality) plays a decisive role in invasion levels, with alien species becoming established more readily in disturbed than in pristine habitats [63,64]. Weizhou Island has endured prolonged intensive anthropogenisation, initially from agricultural expansion and natural resource extraction (e.g., logging), and more recently from urbanization and tourism development [40,50]. These factors are closely associated with the island's disproportionately high numbers of alien, naturalized, and invasive plants. Weizhou Island has also experienced frequent natural disturbances such as typhoons and tropical storms, which can cause destructive impacts in forests, creating large canopy openings [65]. The current high rates of disturbance, whether anthropogenic or natural, likely facilitate the successful establishment of invasive populations on the island. Most of the naturalized species on the island were intentionally introduced as ornamental, agricultural, or forestry species [66]. Among these, escaped ornamental plants represent the largest source of the naturalized aliens. Considering that plant introductions on the island are driven by the boom in tourism-related landscaping [22,27], this pathway likely constitutes the primary source of naturalized species.

5. Conclusions

By providing the first complete inventory of the alien, naturalized, and invasive plants on Weizhou Island, this study contributes to bridging the knowledge gap regarding the occurrence of alien species on South China Sea islands. In total, 203 IAP (55 families and 162 genera), 129 naturalized species (41 families and 100 genera), and 71 invasive species (48 families and 55 genera) were found on Weizhou Island, accounting for 33.4%, 21.2%, and 11.7% of the island's vascular flora, respectively. Asteraceae, Fabaceae, Euphorbiaceae, Amaranthaceae, Solanaceae, and Poaceae dominated the alien, naturalized, and invasive flora. The predominant life forms were perennial and annual herbs, with North America being the most common origin, likely due to the island's tropical climate and climatic similarity to North America. This finding highlights the need for strict control of the introduction of alien herbaceous plants into America. Invasive species were identified in all of the island's habitat types, with higher abundances on abandoned farmland, roadside

areas, and agricultural land. Risk assessment identified 20 high-risk, 16 moderate-risk, and 35 low-risk species. Priority species for management included *Bidens pilosa*, *Ageratum conyzoides*, *Opuntia dillenii*, and *Leucaena leucocephala*. This inventory enriches the global data on island alien flora and will support future monitoring, risk assessment, and invasion management. These findings are critical for protecting island ecosystems and promoting sustainable ecological development.

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Appendix A

Table A1. An inventory of alien flora on Weizhou Island in the northern South China Sea.

Species Name	Family	Status	Life Form	Origin	Risk Value
Ruellia simplex	Acanthaceae	Naturalized	Perennial herb	North America	
Justicia gendarussa	Acanthaceae	Naturalized	Shrub	Asia	
Thunbergia alata	Acanthaceae	Naturalized	Herbaceous vine	Africa	
Amaranthus spinosus	Amaranthaceae	Invasive	Annual herb	North America	38
Amaranthus polygonoides	Amaranthaceae	Invasive	Annual herb	North America	22
Alternanthera philoxeroides	Amaranthaceae	Invasive	Perennial herb	South America	47
Gomphrena globosa	Amaranthaceae	Naturalized	Annual herb	North America	
Celosia argentea	Amaranthaceae	Naturalized	Annual herb	Africa	
Dysphania ambrosioides	Amaranthaceae	Invasive	Perennial herb	North America	34
Gomphrena celosioides	Amaranthaceae	Invasive	Perennial herb	South America	27
Amaranthus viridis	Amaranthaceae	Invasive	Annual herb	North America	33
Hippeastrum striatum	Amaryllidaceae	Casual alien	Perennial herb	South America	
Annona squamosa	Annonaceae	Casual alien	Tree	North America	
Allamanda schottii	Apocynaceae	Casual alien	Woody vine	North America	
Thevetia peruviana	Apocynaceae	Casual alien	Shrub	North America	
Plumeria rubra	Apocynaceae	Casual alien	Shrub	North America	
Nerium oleander	Apocynaceae	Naturalized	Shrub	Africa	
Allamanda cathartica	Apocynaceae	Casual alien	Shrub	North America	
Calotropis procera	Apocynaceae	Casual alien	Shrub	Africa	
Catharanthus roseus	Apocynaceae	Invasive	Shrub	Africa	40
Allamanda blanchetii	Apocynaceae	Casual alien	Shrub	North America	
Syngonium podophyllum	Araceae	Naturalized	Herbaceous vine	North America	
Epipremnum aureum	Araceae	Casual alien	Herbaceous vine	Oceania	
Colocasia esculenta	Araceae	Naturalized	Perennial herb	Asia	
Schefflera macrostachya	Araliaceae	Casual alien	Tree	Oceania	
Hydrocotyle verticillata	Araliaceae	Invasive	Perennial herb	North America	24
Araucaria cunninghamii	Araucariaceae	Casual alien	Tree	Oceania	
Roystonea regia	Arecaceae	Casual alien	Tree	North America	
Ravenea rivularis	Arecaceae	Casual alien	Shrub	Africa	

Table A1. *Cont.*

Species Name	Family	Status	Life Form	Origin	Risk Value
Wodyetia bifurcata	Arecaceae	Casual alien	Tree	Oceania	
Archontophoenix alexandrae	Arecaceae	Casual alien	Tree	Oceania	
Dypsis lutescens	Arecaceae	Casual alien	Shrub	Africa	
Washingtonia filifera	Arecaceae	Casual alien	Tree	North America	
Phoenix sylvestris	Arecaceae	Naturalized	Tree	Asia	
Chlorophytum comosum	Asparagaceae	Casual alien	Perennial herb	Africa	
Asparagus densiflorus	Asparagaceae	Naturalized	Perennial herb	Africa	
Furcraea foetida	Asparagaceae	Casual alien	Perennial herb	North America	
Sansevieria trifasciata	Asparagaceae	Naturalized	Perennial herb	Africa	
Agave sisalana	Asparagaceae	Naturalized	Shrub	North America	
Sansevieria trifasciata var. *laurentii*	Asparagaceae	Casual alien	Perennial herb	Africa	
Beaucarnea recurvata	Asparagaceae	Casual alien	Shrub	North America	
Agave americana	Asparagaceae	Invasive	Perennial herb	North America	21
Dracaena fragrans	Asparagaceae	Casual alien	Shrub	Africa	
Cordyline fruticosa	Asparagaceae	Naturalized	Shrub	Oceania	
Zinnia peruviana	Asteraceae	Invasive	Annual herb	North America	25
Chromolaena odorata	Asteraceae	Invasive	Perennial herb	North America	47
Bidens pilosa	Asteraceae	Invasive	Annual herb	North America	49
Ageratum conyzoides	Asteraceae	Invasive	Annual herb	North America	48
Praxelis clematidea	Asteraceae	Invasive	Annual herb	South America	49
Synedrella nodiflora	Asteraceae	Invasive	Perennial herb	North America	34
Sonchus oleraceus	Asteraceae	Naturalized	Annual herb	Africa	
Eclipta prostrata	Asteraceae	Naturalized	Perennial herb	North America	
Sphagneticola trilobata	Asteraceae	Invasive	Perennial herb	South America	45
Galinsoga parviflora	Asteraceae	Invasive	Annual herb	North America	29
Mikania micrantha	Asteraceae	Invasive	Herbaceous vine	North America	42
Erigeron canadensis	Asteraceae	Invasive	Annual herb	North America	46
Crassocephalum crepidioides	Asteraceae	Invasive	Annual herb	Africa	41
Erigeron annuus	Asteraceae	Invasive	Annual herb	North America	43
Parthenium hysterophorus	Asteraceae	Invasive	Annual herb	North America	39
Tridax procumbens	Asteraceae	Invasive	Perennial herb	North America	25
Tithonia diversifolia	Asteraceae	Invasive	Shrub	North America	30
Symphyotrichum subulatum	Asteraceae	Invasive	Annual herb	North America	46
Impatiens balsamina	Balsaminaceae	Naturalized	Annual herb	Asia	
Basella alba	Basellaceae	Naturalized	Herbaceous vine	North America	
Anredera cordifolia	Basellaceae	Invasive	Herbaceous vine	North America	33
Begonia cucullata var. *hookeri*	Begoniaceae	Casual alien	Perennial herb	North America	
Kigelia africana	Bignoniaceae	Casual alien	Tree	Africa	
Handroanthus chrysanthus	Bignoniaceae	Casual alien	Tree	North America	
Spathodea campanulata	Bignoniaceae	Naturalized	Tree	Africa	
Pyrostegia venusta	Bignoniaceae	Naturalized	Woody vine	North America	
Heliotropium indicum	Boraginaceae	Naturalized	Annual herb	South America	
Ananas comosus	Bromeliaceae	Casual alien	Perennial herb	South America	
Selenicereus undatus	Cactaceae	Naturalized	Shrub	North America	
Cereus peruvianus	Cactaceae	Naturalized	Shrub	South America	
Opuntia dillenii	Cactaceae	Invasive	Shrub	North America	44
Opuntia cochenillifera	Cactaceae	Naturalized	Shrub	North America	
Canna generalis	Cannaceae	Casual alien	Perennial herb	Europe	
Canna indica	Cannaceae	Naturalized	Perennial herb	North America	
Carica papaya	Caricaceae	Naturalized	Shrub	North America	
Stellaria aquatica	Caryophyllaceae	Naturalized	Perennial herb	Asia	
Drymaria cordata	Caryophyllaceae	Naturalized	Annual herb	North America	
Casuarina equisetifolia	Casuarinaceae	Naturalized	Tree	Asia	
Terminalia neotaliala	Combretaceae	Casual alien	Tree	Africa	
Tradescantia spathacea	Commelinaceae	Naturalized	Perennial herb	North America	
Ipomoea batatas	Convolvulaceae	Naturalized	Herbaceous vine	North America	
Ipomoea nil	Convolvulaceae	Invasive	Herbaceous vine	North America	24
Ipomoea aquatica	Convolvulaceae	Naturalized	Herbaceous vine	Africa	

Table A1. *Cont.*

Species Name	Family	Status	Life Form	Origin	Risk Value
Ipomoea cairica	Convolvulaceae	Invasive	Herbaceous vine	Africa	43
Kalanchoe daigremontiana	Crassulaceae	Naturalized	Perennial herb	Africa	
Bryophyllum pinnatum	Crassulaceae	Invasive	Perennial herb	Africa	31
Kalanchoe gastonis-bonnieri	Crassulaceae	Casual alien	Perennial herb	Africa	
Benincasa hispida	Cucurbitaceae	Casual alien	Herbaceous vine	Asia	
Luffa acutangula	Cucurbitaceae	Casual alien	Herbaceous vine	Asia	
Cucumis sativus	Cucurbitaceae	Casual alien	Herbaceous vine	Asia	
Momordica charantia	Cucurbitaceae	Casual alien	Herbaceous vine	Asia	
Cucurbita moschata	Cucurbitaceae	Casual alien	Herbaceous vine	North America	
Luffa aegyptiaca	Cucurbitaceae	Casual alien	Herbaceous vine	Asia	
Citrullus lanatus	Cucurbitaceae	Casual alien	Herbaceous vine	Africa	
Euphorbia heterophylla	Euphorbiaceae	Invasive	Perennial herb	North America	21
Ricinus communis	Euphorbiaceae	Invasive	Shrub	Africa	34
Codiaeum variegatum	Euphorbiaceae	Casual alien	Shrub	Asia	
Jatropha integerrima	Euphorbiaceae	Casual alien	Shrub	North America	
Euphorbia hirta	Euphorbiaceae	Invasive	Annual herb	North America	35
Excoecaria cochinchinensis	Euphorbiaceae	Casual alien	Shrub	Asia	
Pedilanthus tithymaloides	Euphorbiaceae	Casual alien	Shrub	North America	
Euphorbia antiquorum	Euphorbiaceae	Invasive	Shrub	Asia	21
Euphorbia neriifolia	Euphorbiaceae	Casual alien	Shrub	North America	
Manihot esculenta	Euphorbiaceae	Naturalized	Shrub	South America	
Euphorbia milii	Euphorbiaceae	Naturalized	Shrub	Africa	
Euphorbia hypericifolia	Euphorbiaceae	Invasive	Annual herb	North America	23
Euphorbia cyathophora	Euphorbiaceae	Invasive	Perennial herb	North America	24
Euphorbia pulcherrima	Euphorbiaceae	Invasive	Shrub	North America	21
Senna alata	Fabaceae	Invasive	Shrub	North America	30
Acacia auriculiformis	Fabaceae	Naturalized	Tree	Oceania	
Desmanthus virgatus	Fabaceae	Invasive	Perennial herb	North America	29
Delonix regia	Fabaceae	Naturalized	Tree	Africa	
Mimosa bimucronata	Fabaceae	Invasive	Shrub	North America	39
Mimosa pudica	Fabaceae	Invasive	Perennial herb	North America	34
Senna surattensis	Fabaceae	Naturalized	Shrub	Asia	
Erythrina crista-galli	Fabaceae	Casual alien	Tree	North America	
Vigna unguiculata	Fabaceae	Casual alien	Herbaceous vine	Africa	
Arachis hypogaea	Fabaceae	Casual alien	Perennial herb	South America	
Vigna radiata	Fabaceae	Naturalized	Herbaceous vine	Asia	
Acacia mangium	Fabaceae	Casual alien	Tree	Oceania	
Cassia bakeriana	Fabaceae	Casual alien	Tree	Asia	
Senna bicapsularis	Fabaceae	Invasive	Shrub	North America	25
Sesbania cannabina	Fabaceae	Invasive	Annual herb	Oceania	35
Senna occidentalis	Fabaceae	Invasive	Perennial herb	North America	24
Caesalpinia pulcherrima	Fabaceae	Naturalized	Shrub	North America	
Leucaena leucocephala	Fabaceae	Invasive	Tree	North America	49
Mentha spicata	Lamiaceae	Naturalized	Perennial herb	Africa	
Tectona grandis	Lamiaceae	Naturalized	Tree	Asia	
Lagerstroemia speciosa	Lythraceae	Casual alien	Tree	Asia	
Punica granatum	Lythraceae	Casual alien	Shrub	Europe	
Sonneratia apetala	Lythraceae	Invasive	Tree	Asia	25
Michelia alba	Magnoliaceae	Casual alien	Tree	Asia	
Malvaviscus penduliflorus	Malvaceae	Casual alien	Shrub	North America	
Triumfetta rhomboidea	Malvaceae	Naturalized	Shrub	North America	
Pachira glabra	Malvaceae	Casual alien	Tree	North America	
Sida acuta	Malvaceae	Invasive	Perennial herb	Asia	22
Abelmoschus esculentus	Malvaceae	Naturalized	Perennial herb	Asia	
Ceiba speciosa	Malvaceae	Casual alien	Tree	North America	
Malvastrum coromandelianum	Malvaceae	Invasive	Perennial herb	North America	41
Sida cordata	Malvaceae	Naturalized	Perennial herb	Asia	
Maranta arundinacea	Marantaceae	Casual alien	Perennial herb	North America	
Thalia dealbata	Marantaceae	Invasive	Perennial herb	North America	21

Table A1. *Cont.*

Species Name	Family	Status	Life Form	Origin	Risk Value
Artocarpus heterophyllus	Moraceae	Casual alien	Tree	Asia	
Ficus lyrata	Moraceae	Casual alien	Tree	Africa	
Ficus religiosa	Moraceae	Naturalized	Tree	Asia	
Melaleuca cajuputi subsp. *cumingiana*	Myrtaceae	Casual alien	Tree	Asia	
Psidium guajava	Myrtaceae	Naturalized	Tree	North America	
Callistemon rigidus	Myrtaceae	Casual alien	Tree	Oceania	
Xanthostemon chrysanthus	Myrtaceae	Casual alien	Tree	Oceania	
Eucalyptus grandis × *urophylla*	Myrtaceae	Casual alien	Tree	Oceania	
Syzygium samarangense	Myrtaceae	Casual alien	Tree	Asia	
Bougainvillea glabra	Nyctaginaceae	Naturalized	Woody vine	North America	
Bougainvillea spectabilis	Nyctaginaceae	Naturalized	Shrub	North America	
Mirabilis jalapa	Nyctaginaceae	Invasive	Perennial herb	North America	24
Jasminum sambac	Oleaceae	Casual alien	Woody vine	Asia	
Oxalis corymbosa	Oxalidaceae	Invasive	Perennial herb	North America	35
Averrhoa carambola	Oxalidaceae	Casual alien	Tree	Asia	
Pandanus utilis	Pandanaceae	Casual alien	Shrub	Africa	
Passiflora edulis	Passifloraceae	Naturalized	Herbaceous vine	North America	
Phyllanthus amarus	Phyllanthaceae	Naturalized	Annual herb	North America	
Phyllanthus tenellus	Phyllanthaceae	Invasive	Annual herb	Africa	25
Pittosporum tobira	Pittosporaceae	Naturalized	Shrub	Asia	
Plumbago auriculata	Plumbaginaceae	Casual alien	Herbaceous vine	Africa	
Axonopus compressus	Poaceae	Invasive	Perennial herb	North America	32
Saccharum officinarum	Poaceae	Casual alien	Perennial herb	Asia	
Paspalum vaginatum	Poaceae	Naturalized	Perennial herb	North America	
Spartina alterniflora	Poaceae	Invasive	Perennial herb	North America	40
Cenchrus echinatus	Poaceae	Invasive	Annual herb	North America	36
Bambusa blumeana	Poaceae	Casual alien	Bamboo	Asia	
Panicum repens	Poaceae	Invasive	Perennial herb	Africa	35
Paspalum distichum	Poaceae	Invasive	Perennial herb	North America	30
Zea mays	Poaceae	Casual alien	Annual herb	North America	
Pontederia crassipes	Pontederiaceae	Invasive	Perennial herb	North America	47
Portulaca grandiflora	Portulacaceae	Naturalized	Annual herb	South America	
Portulaca umbraticola	Portulacaceae	Casual alien	Annual herb	North America	
Portulaca pilosa	Portulacaceae	Invasive	Perennial herb	North America	26
Portulaca quadrifida	Portulacaceae	Casual alien	Annual herb	North America	
Macadamia integrifolia	Proteaceae	Casual alien	Tree	Oceania	
Spermacoce remota	Rubiaceae	Invasive	Perennial herb	North America	25
Spermacoce alata	Rubiaceae	Invasive	Annual herb	North America	46
Richardia scabra	Rubiaceae	Invasive	Annual herb	North America	37
Manilkara zapota	Sapotaceae	Casual alien	Tree	North America	
Solanum lycopersicum	Solanaceae	Naturalized	Perennial herb	North America	
Physalis angulata	Solanaceae	Invasive	Annual herb	North America	25
Capsicum annuum	Solanaceae	Naturalized	Perennial herb	North America	
Solanum americanum	Solanaceae	Invasive	Perennial herb	North America	30
Solanum torvum	Solanaceae	Invasive	Shrub	North America	27
Nicotiana tabacum	Solanaceae	Casual alien	Perennial herb	North America	
Datura metel	Solanaceae	Invasive	Perennial herb	North America	25
Cestrum nocturnum	Solanaceae	Naturalized	Shrub	North America	
Solanum capsicoides	Solanaceae	Invasive	Perennial herb	South America	27
Datura stramonium	Solanaceae	Invasive	Annual herb	North America	33
Ravenala madagascariensis	Strelitziaceae	Casual alien	Perennial herb	Africa	
Pilea microphylla	Urticaceae	Invasive	Perennial herb	South America	28
Duranta erecta	Verbenaceae	Naturalized	Shrub	North America	
Stachytarpheta jamaicensis	Verbenaceae	Invasive	Shrub	North America	23
Lantana camara	Verbenaceae	Invasive	Shrub	North America	47
Cissus verticillata	Vitaceae	Naturalized	Woody vine	North America	
Vitis vinifera	Vitaceae	Casual alien	Woody vine	Asia	

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