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Potential risks of Invasive Alien Plant Species on native plant biodiversity in Sri Lanka due to climate change

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ABSTRACT

There have been few studies investigating the implications of the potential distribution of plant invasions on native biodiversity due to climate change. In this study, we used combined climatic suitability maps of 14 priority Invasive Alien Plant Species (IAPS) in Sri Lanka under the current climate and under Representative Concentration Pathway (RCP) 4.5 and RCP 8.5 climate scenarios for 2050 to examine the potential risks of plant invasions on native plant biodiversity. We used three types of layers defining plant biodiversity patterns for Sri Lanka; (i) nine zones of plant endemism (zones of high floristic richness and endemicity), (ii) eleven threatened endemic taxa and (iii) eight forest-related ecosystems. Our results reveal that the biodiversity-rich zones of endemism are at potentially high-risk under climate change. The potential risks on threatened endemic plants are likely to reduce slightly under an RCP 4.5 low-emissions scenario and be intensified under an RCP 8.5 high-emissions scenario. Forest-related ecosystems are vulnerable to IAPS to varying degrees; dry zone ecosystems are predicted to increase the risks of IAPS, while those in the wet zone are envisioned to decrease. Overall, our findings suggest that the potential risks of plant invasions on native plant biodiversity differ significantly under projected climate change. Greater understanding of the potential risks of IAPS at an early stage is important in prioritising future conservation measures for effective protection of native biodiversity.

KEYWORDS

invasive alien plant species; native plant biodiversity; potential climatic suitability; species distribution modelling; threatened endemic plants; zones of plant endemism

1. Introduction

Climate change is undeniable and its impact on global biodiversity is well recognised (IPCC 2014). Projected climatic changes may directly impact biodiversity and ecosystem services, leading to species extinctions (Bellard et al. 2012). In addition, climate change can have a significant impact due to alterations in the distribution and ecological niche shift of invasive species which ultimately leads to substantial changes of biodiversity patterns (O'donnell et al. 2012; Bellard et al. 2018). Many invaders will spread into new areas and the range sizes they occupy will vary based on factors such as taxonomic group and the scale of study (Bellard et al. 2018). Ahmad et al. (2019) investigated the potential distribution and niche dynamics of *Parthenium hysterophorus*, a notorious plant invader in India, in response to climate change. Such findings provide insights into understanding their invasion potential and are fundamental in developing management strategies. IAPS, a leading direct cause of environmental change (Vitousek et al. 1997), is considered one of the major challenges to ecosystem sustainability, ecological processes, and ecosystem services (Dukes and Mooney 1999; McNeely 2004). Therefore, it is important to assess and understand the potential risks of IAPS and take urgent action to mitigate such impacts, especially to high conservation value areas requiring native biodiversity protection (Slodowicz et al. 2018). However, measures to prevent the establishment and dispersal of exotic plant invaders have been challenging despite many control and management measures (Mack et al. 2000). Global biodiversity indicators confirm that the impact of biological invasions in most ecosystems, due to increasing trade and travel, is substantial and has not declined despite unprecedented control efforts (McGeoch et al. 2010; Millennium Ecosystem Assessment 2005; Butchart et al. 2010).

IAPS can dramatically deplete native biodiversity via several mechanisms such as competition, predation, habitat alteration, herbivory, hybridisation and other indirect means (Gaertner et al. 2009; Waser, Splinter, and van der Meer 2015; Manchester and Bullock 2000). Biological invasions are recognised as the second most common threat to species that are subject to extinction after the discovery of America (Bellard, Cassey, and Blackburn 2016). Research has clearly shown that

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IAPS can exclude native species, particularly rare natives, due to their more aggressive competitive ability (Houlahan and Findlay 2004). Additionally, they can have adverse impacts on important ecological processes (Allison and Vitousek 2004). Nevertheless, the risks of IAPS have not been adequately studied and understood, especially their influence on ecosystem services (i.e. provisioning, regulating, and cultural), as IAPS impacts are not comprehensively defined (Richardson and Van Wilgen 2004; Pejchar and Mooney 2009; Jeschke et al. 2014).

Plant invasion has caused a substantial impact on native biodiversity, particularly in the island countries (Sax, Gaines, and Brown 2002). In many island nations, the majority of modern native species extinctions accompanying alien plant invasions relates to endemic species (Bellard, Cassey, and Blackburn 2016). It is considered the single most important driver of species extinction in islands where biodiversity is unique, fragile and vulnerable to extinction compared to continental species (Reaser et al. 2007). Assessment of potential risks to plant biodiversity in islands is rare due to limited scientific research in island countries and reducing these risks is a great challenge for conservation planners (Taylor and Kumar 2016; Reaser et al. 2007; Thuiller 2007). Failure to predict and assess the risks of plant invasions on the future of native biodiversity in those countries may hinder more effective management interventions (Wale and Yalew 2010).

Species distribution modelling can play an important role in assessing potential risks of IAPS in island countries where such impacts are poorly understood (Kariyawasam, Kumar, and Ratnayake 2019b). Species Distribution Models (SDMs) can be used to identify areas with potential plant invasion and those with high risk of IAPS (Kulhanek, Leung, and Ricciardi 2011). Such information is vital for developing control and management strategies. Though limited, SDMs provide valuable information and insights on potential impacts of plant invasions, particularly when actual impact data are not available or accessible (Ricciardi 2003). Potential risks from IAPS to native biodiversity can be evaluated by examining the climatic suitability maps of IAPS distribution. In a companion paper, we demonstrated how to simulate climate change effects on potential IAPS distribution in Sri Lanka using the Maximum Entropy (MaxEnt) modelling technique and, in that paper, we defined potential high-risk areas of IAPS (see Kariyawasam, Kumar, and Ratnayake (2019a) for details). We individually modelled climatic suitability of habitat for 14 nationally-recognised terrestrial IAPS in the country under current and projected climate change (RCP 4.5 and RCP 8.5) for 2050, and developed combined climatic suitability maps ("heat maps") that show IAPS concentration areas. Defining IAPS concentration areas is significantly important for setting priorities for allocation of limited resources (Coates and Atkins 2001).

Sri Lanka is a tropical island country with high biodiversity levels that are currently challenged by plant invasions. The objective of the current study was to evaluate how the potential spatio-temporal changes of 14 priority IAPS can influence, or affect, native plant biodiversity across the country under projected climate change scenarios. Our approach was to use potential climatic suitability (i.e. number of IAPS overlapped) as a measure to assess the potential risks from IAPS to native plant biodiversity. We selected eleven threatened endemic genera and their habitats (nine zones of endemism and eight forest-related ecosystems) that may be potentially at risk by the distribution of IAPS under projected climate models. Designated protected areas were not considered in this analysis since many such areas are scattered and represent relatively low endemic and threatened plant species richness compared to the zones of endemism (see also Slodowicz et al. (2018)). The significance of this study is that no previous study has been undertaken in Sri Lanka to examine the potential risks to the future of native plant biodiversity by IAPS under current climate change projections. The selected 14 priority IAPS are common invasive species in many countries in the region; similar invasion dynamics could also be expected in those countries. Thus, this study could have implications on a much wider geographic scale.

2. Materials and methods

2.1 Study area

Sri Lanka is a tropical island in the Indian Ocean, with an area of 65,610 km^2. Despite its relatively small size, the country harbours rich biodiversity due to a wide variety of climatic, topographic and soil factors (MoFE 1999). Regarding many plants and animals groups, Sri Lanka has an exceptionally high species diversity per unit area compared with other countries in South Asia (Baldwin 1991). There are 3,154 flowering plant species of which 894 (over 28%) are endemic, belonging to 186 families (MOE 2012). The distribution pattern of endemic flora in Sri Lanka shows a specific geographical pattern. According to Wijesundara and Perera (2016), many endemic species are concentrated in nine specific zones of endemism: Central Highlands, South-west Wet Zone, Eastern Highlands, Northern Highlands, Ritigala, Dolukanda, Yala, Wilpattu, and Jaffna (Figure 1). Each

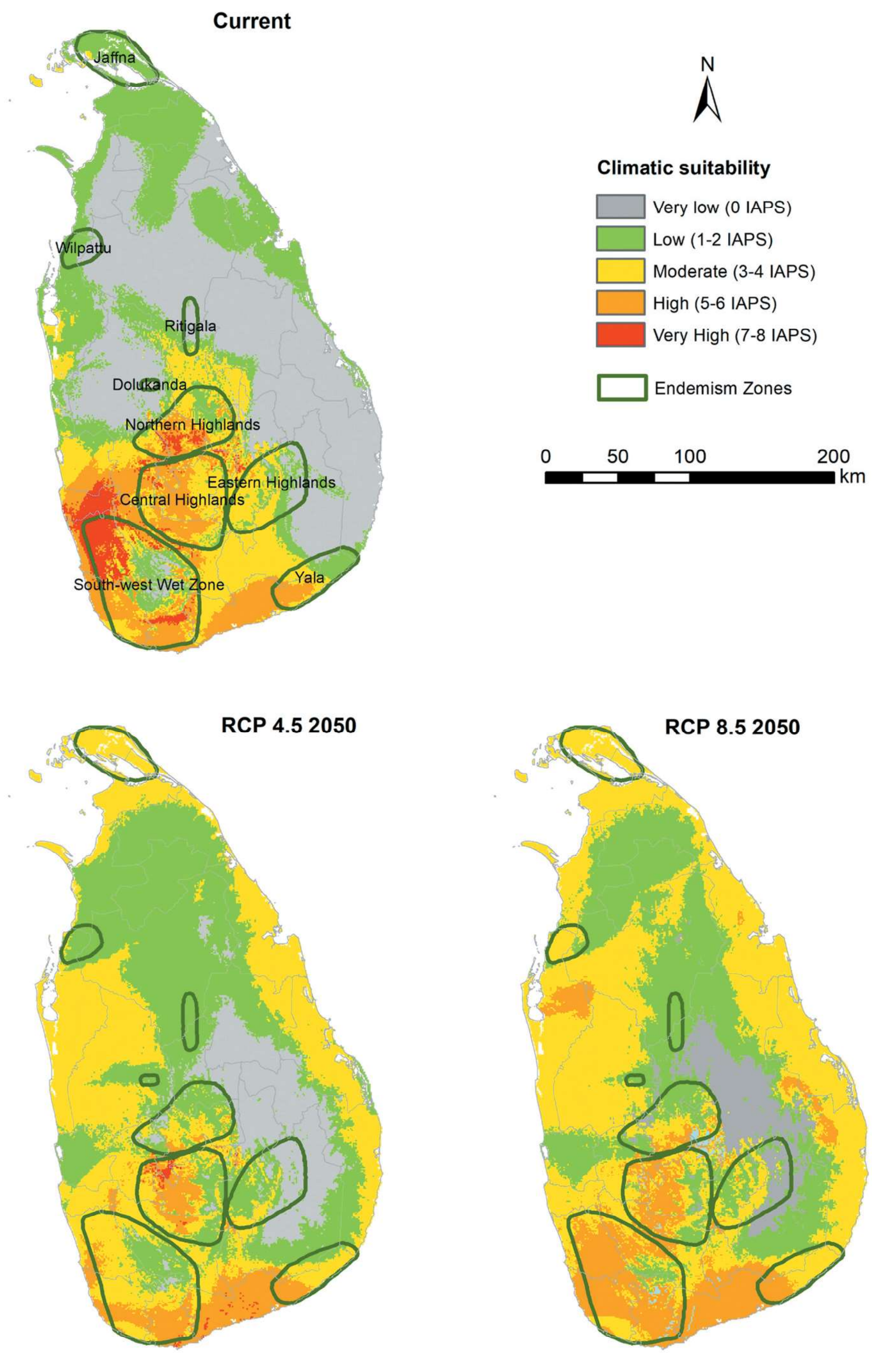

Figure 1. Zones of plant endemism overlaid on potential current and future climatic suitability for IAPS establishment in Sri Lanka under current climate and future climate scenarios.

of these zones of endemism harbours a range from 689 to 14 endemic plant species, representing 77% and 2% endemic flora of the country, respectively (Table S1). The threatened status of endemic plants of the country has been assessed in the national red list preparation process and most of the threatened endemic plants are concentrated in the wet zone of the country (MOE 2012). Sri Lanka has a rich forest-related ecosystem diversity, varying from Wet Evergreen Forests to Dry Thorn Forests (MoFE 1999).

2.2 Background to the study

The MaxEnt species distribution model was used to identify the invasion dynamics of 14 priority IAPS in

Sri Lanka under current climate and projected climate change (RCP 4.5 and RCP 8.5) for 2050 (Kariyawasam, Kumar, and Ratnayake 2019a). These included; *Alstonia macrophylla, Clidemia hirta, Annona glabra, Lantana camara, Dillenia suffruticosa, Leucaena leucocephala, Mimosa pigra, Opuntia dillenii, Panicum maximum, Parthenium histerophorus, Austroeupatorium inulifolium, Prosopis juliflora, Sphagneticola trilobata*, and *Ulex europaeus* (Table S2). The modelling used 1,460 geo-referenced species occurrence records and a set of 7 non-redundant environmental variables (Table S3). Cross-validation was carried out with 10 replicates, 1000 maximum iterations, and 3 feature types (linear, quadratic, and hinge); other parameters were kept at default values. In ArcMap, suitability maps for species were classified using widely accepted 'maximum training sensitivity plus specificity logistic threshold'. Classified layers were summed to develop concerted maps of climatic suitability ("heat maps") which were then manually grouped into 5 classes: very low (0 IAPS), low (1-2 IAPS), moderate (3-4 IAPS), high (5-6 IAPS) and very high (7-8 IAPS) - no location had a projection of more than 8 IAPS. From this, we generated three classified maps of combined climatic suitability of fourteen IAPS under current and future climate scenarios. Findings revealed that some IAPS, viz. *A. macrophylla, A. glabra, D. suffruticosa, L. leucocephala, M. pigra, O. dillenii* and *P. histerophorus* are projected to enlarge the climatic suitability under future scenarios while some others, viz. *A. inulifolium, C. hirta, L. camara, P. maximum, P. juliflora, S. trilobata*, and *U. europaeus* are projected to decline. However, potential range expansions were more conspicuous than range contractions. An area susceptible to multiple IAPS establishment was predicted in the South and West Wet Zone of the country. Overall, the total area potentially supports more than three IAPS (moderate, high, and very high classes) which is approximately 33% of the area of the country under the current climate and is predicted to increase by 45% and 90% under RCP 4.5 and RCP 8.5 for 2050, respectively. Similarly, the total area potentially supports less than two IAPS (very low and low classes), which is as high as 67% of the area of the country under the current climate and is predicted to decrease by 22% and 44% under RCP 4.5 and RCP 8.5 for 2050, respectively. These invasion dynamics suggest possible intensified risks from IAPS across Sri Lanka in the future.

2.3 Risks of IAPS on zones of endemism

Areas with high suitability for IAPS establishment can potentially result in a relatively high-risk on native biodiversity. Therefore, we used the area of climatic suitability classes in a defined geographic entity (zones of endemism) to identify the risk. The map of zones of plant endemism of Sri Lanka was overlaid on the combined map of climatic suitability of 14 IAPS in ArcMap (Version 10.4.1) to identify the likelihood of IAPS distribution within these zones. Initially, we used a combined map of climatic suitability in the current climate and, subsequently, we used the projected layers for 2050 under RCP 4.5 and RCP 8.5 climate scenarios. Areas of climatic suitability classes (very high to very low), within zones of endemism, were calculated under current and future climate scenarios for assessing the potential risks of IAPS to those zones.

2.4 Risks of IAPS on threatened endemic taxa

Threatened endemic plants of Sri Lanka are mainly concentrated in the South-west Wet Zone. Thus, we investigated how the potential changes of climatic suitability of 14 IAPS may influence the threatened endemic plants in the south-west. In this study, we used 423 occurrences of 11 threatened endemic genera belonging to 8 plant families, namely; *Adrorhizon* (Orchidaceae), *Davidsea* (Poaceae), *Diyaminauclea* (Rubiaceae), *Hortonia* (Monimiaceae), *Leucocodon* (Rubiaceae), *Loxococcus* (Arecaceae), *Nargedia* (Rubiaceae), *Phoenicanthus* (Annonaceae), *Schumacheria* (Dilleniaceae), *Scyphostachys* (Rubiaceae), and *Stemonoporus* (Dipterocarpaceae) (MOE 2012; Wijesundara and Perera 2016). The respective climatic suitability class of occurrence records was identified under current climate and under future climate scenarios for 2050. This exercise was applied individually for 11 threatened endemic genera to see how suitability may change among taxonomic groups, and then for all aggregated occurrences of 11 genera to see the overall pattern of suitability change. Our approach was to examine the climatic suitability of habitats of these threatened endemic taxa and to understand the changes in suitability under climate change.

2.5 Risks of IAPS on forest-related ecosystems

Ecosystems, which are a major component of biodiversity and encompass its characteristic vegetation and biogeography, can be potentially impacted differently by IAPS. We examined the potential risks of IAPS on several forest-related ecosystems of Sri Lanka. Our approach was to examine the area changes in different climatic suitability classes in each ecosystem under projected climate change scenarios. Eight ecosystem types were considered in this assignment: (i) Lowland Rainforests, (ii) Dry Patana Grasslands, (iii) Dry

Monsoon Forests, (iv) Dry Deciduous Thorn Scrub, (v) Moist Monsoon Forests, (vi) Montane Forests, (vii) Submontane Forests and (viii) Wet Patana Grasslands. Climatic suitability maps were correlated with individual ecosystem layers to calculate areas of climatic suitability classes (very high to very low) in each ecosystem under current and future climate scenarios for 2050. Based on area changes in climatic suitability classes, the potential risks on the ecosystem under different climate projections were identified.

3. Results

3.1 Risks of IAPS on zones of endemism

Figure 1 shows map zones of plant endemism in Sri Lanka overlaid on the combined map of climatic suitability of IAPS in current and future climate scenarios (RCP 4.5 and 8.5) for 2050. The areas of climatic suitability within nine zones of endemism were calculated (Figure 2). Differences in potential climatic suitability for IAPS invasion in nine zones of plant endemism were observed spatially and temporally. Under current climate conditions, all zones of endemism, excluding Wilpattu, represented moderate to very high (3-8) climatic suitability for IAPS establishment - though this suitability is less pronounced in Ritigala, Dolukanda and Jaffna zones of endemism. By 2050, under RCP 4.5 and RCP 8.5 scenarios, this suitability is represented in all zones of endemism other than Ritigala. Similarly, in the current climate, low and very low IAPS (0-2) climatic suitability is represented in all zones of endemism to varying degrees though suitability is completely absent in the Jaffna zone of endemism by 2050 under the two future climate scenarios. The Central Highlands zone of endemism, which harbours the highest numbers of endemic (689) and unique endemic (106) plant species and represents 77% of Sri Lanka's total endemic plant diversity (Table S1) (Wijesundara and Perera 2016), is at potentially high-risk. Under current climate conditions, over 96% of the area in the Central Highlands zone of endemism shows moderate to very high climatic suitability for IAPS establishment and no area is predicted to be free from potential risks. Consequently, 106 unique endemic plants that are confined to this geographic zone, and do not exist in any other part of the country or other habitat in the world, are potentially at risk. Under RCP 4.5 and RCP 8.5 scenarios for 2050, approximately 71% and 79% of the area in the Central Highlands zone of endemism show moderate to very high climatic suitability, respectively. This means the areas of very high, high, and moderate classes are predicted to decrease slightly in the future while low and very low classes are predicted to have a modest increase - suggesting that overall potential risks under projected climate change would decline.

The largest zone of endemism, South-west Wet Zone, which harbours the second-highest number of endemic (527) and unique endemic (46) plant species and represents 59% of the total endemic flora of the country, is also at high-risk. Under the current climate, over 75% of the total area in the South-west Wet Zone's scope of endemism shows moderate to very high (3-8 IAPS) climatic suitability. Under the RCP 4.5 climatic scenario, the area of moderate to very high climatic suitability is likely to remain the same (75%) though the area of very high suitability

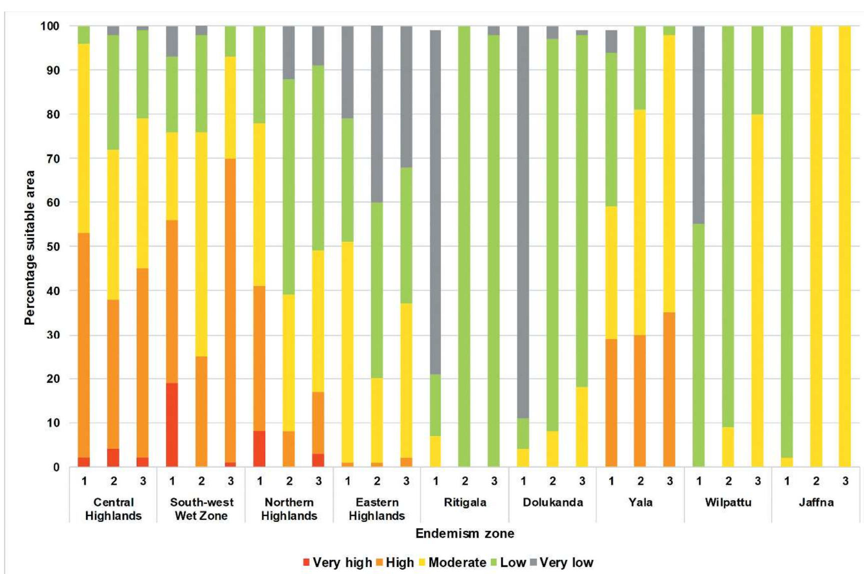

Figure 2. Percentage area of potential climatic suitability for fourteen priority IAPS establishment in nine zones of plant endemism of Sri Lanka under current and future climate scenarios, where 1: Current Climate; 2: RCP 4.5 for 2050; 3: RCP 8.5 for 2050.

class is predicted to decrease. Under RCP 8.5, the area of moderate to very high climatic suitability is predicted to become 93% of the total area, mainly due to the increased area of the high suitability class. Therefore, overall risks of IAPS are predicted to increase substantially under the high emission scenario compared with the low emission one. The Northern Highlands zone of endemism, which supports the third-highest number of endemic (426) and unique endemic (28) plant species and represents 48% of the total endemic flora of Sri Lanka (Table S3), is also predicted to be at risk from the potential spread of IAPS. The moderate to very high suitability area in the Northern Highlands zone of endemism is predicted as 78% with the current climate; this suitability area reduces to 39% and 49% under RCP 4.5 and RCP 8.5 scenarios, respectively. This suitability reduction is mainly due to the declining area of the high suitability class. Areas of low and very low suitability are predicted to increase in this zone of endemism under both scenarios suggesting, overall, potentially decreased risks. Eastern Highlands zone of endemism is also predicted to decrease in suitability in the future which is mainly due to the conversion of the moderate suitability areas to low and very low areas under projected climate models. The smallest zone of endemism, Dolukanda, contains 51 endemic plant species and boasts the highest endemic plant richness. In the current climate, 89% of the total area in this zone is modelled to have very low (0) suitability for IAPS spread. Under projected climate changes, this region is predicted to transition to low suitability due to potential invasion by one or two IAPS. Ritigala, Wilpattu, Yala, and Jaffna zones of endemism have also shown projected increases in their climatic suitability for potential IAPS invasion under climate change. Overall, zones of endemism distributed mainly in the wet region of the country are likely to decrease in climatic suitability for potential IAPS establishment which suggests a declining risk of IAPS in the future. Candidates located in the dry zone are likely to increase in suitability and, thus, increase the risk to native plant biodiversity.

3.2 Risks of IAPS on threatened endemic taxa

Distribution of occurrences of threatened endemic taxa was mostly restricted to the defined zones of endemism in south-west Sri Lanka. We examined the distribution pattern of suitability for occurrences under current and future climate scenarios for the total number of occurrences (Figure 3) and, individually, for genera (Figure S4) and then observed any differences. Four taxa (*Adrorhizon, Davidsea, Diyaminauclea*, and *Hortonia*) are projected to have decreased risks in the future under both RCP scenarios and so these species should have a relatively lower risk from IAPS. All other eight taxa are projected to have decreased risks under the RCP 4.5 scenario and increased risks under the RCP 8.5 scenario. Generally, the potential risks of IAPS on threatened endemic plants are likely to reduce a little under RCP 4.5 due to decreased climatic suitability in very high and high classes (Figure 3). However, data suggest that the potential risks are likely to intensify under RCP 8.5 due to significantly increased suitability in the high climatic suitability class.

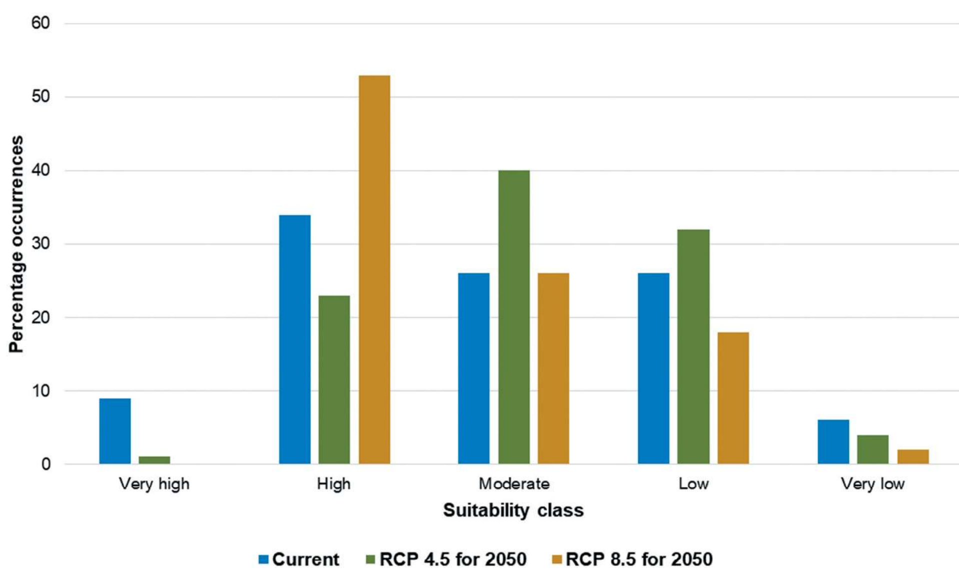

Figure 3. Distribution of 423 occurrences belonging to 11 threatened endemic genera in different climatic suitability classes under current and future (RCP 4.5 and RCP 8.5) climate scenarios. The graph shows percentage number of occurrences in each climatic suitability class.

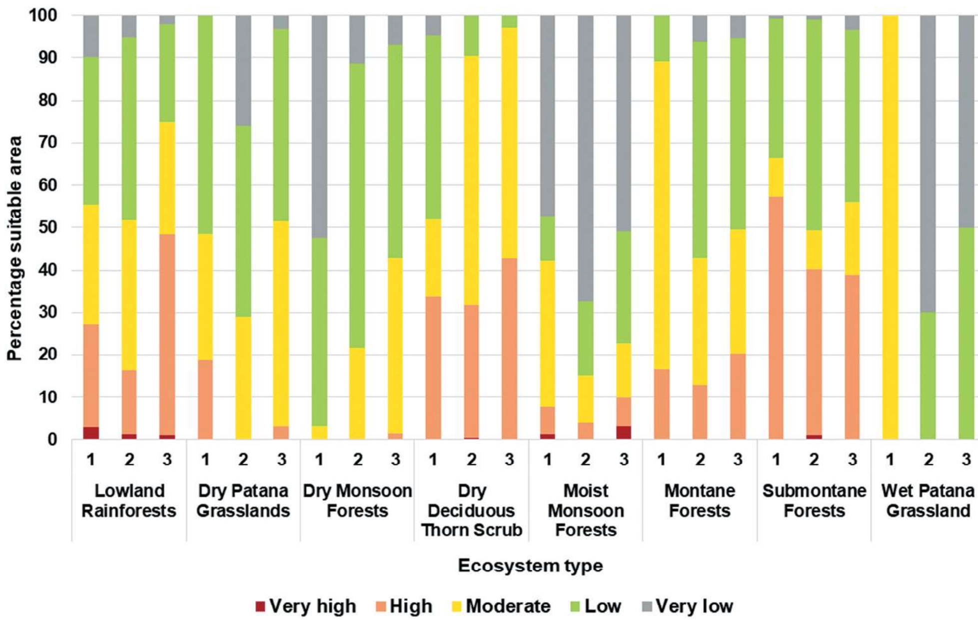

Figure 4. Percentage area of potential climatic suitability for 14 priority IAPS establishment in selected forest related ecosystems of Sri Lanka under current and future climate scenarios, where 1: Current Climate; 2: RCP 4.5 for 2050; 3: RCP 8.5 for 2050.

3.3 Risks of IAPS on forest-related ecosystems

Results reveal that all ecosystems investigated are susceptible to IAPS establishment of different magnitudes under current and future climate scenarios; Figure 4 illustrates how this varies. Moist Monsoon Forests, Lowland Rainforests, Montane Forests, Submontane Forests, and Wet and Dry Patana Grasslands are predicted to decrease in suitability for IAPS establishment by 2050 under climate change probabilities. However, Lowland Rainforests are predicted to increase in suitability for IAPS under the RCP 8.5 scenario. Dry Deciduous Thorn Scrub and Dry Monsoon Forests, which are spread extensively throughout the dry zone of Sri Lanka, are predicted to be at increased risk of IAPS under climate change modelling. Of all the evaluated ecosystems, the Moist Monsoon Forests and Wet Patana Grasslands are predicted to significantly decrease in suitability for IAPS, particularly under the RCP 4.5 low emissions scenario and thus reasonably safe from potential risks of IAPS. Sinharaja Lowland Rainforest, the only remaining pristine rainforest in south-west Sri Lanka, is predicted to be safe under current climate though the risk from IAPS is predicted to rise slightly in the future under projected climate changes.

4. Discussion

4.1 Risks of IAPS on zones of endemism

Much of Sri Lanka's plant biodiversity is concentrated in the forests and associated ecosystems in the south-west of the country (Ashton et al. 2001). Zones of plant endemism, which provide a good representation of flowering plants with conservation concern, are also concentrated in the south-west of Sri Lanka (Wijesundara and Perera 2016). Our modelling study revealed that this area has huge potential for multiple IAPS establishment (Kariyawasam, Kumar, and Ratnayake 2019a) and potentially significant and challenging consequences for threatened endemic plant biodiversity. It is generally acknowledged that it is the *climate* that primarily controls the geographical distribution of plants across landscapes (Woodward 1987; Taylor et al. 2012; Grinnell 1917). IAPS have a propensity to establish themselves in warm, dry - and damp areas - suggesting that IAPS distribution in the future could be mostly driven by climate change (Tripathi, Behera, and Roy 2019). South-west Sri Lanka belongs to the wet zone of the country and this area may attract many plant invaders as they can easily establish themselves in gaps that can be created in wet, damp environments (Thompson, Hodgson, and Rich 1995). Our findings suggest that the potential risks of IAPS on zones of endemism located in the dry zone and wet zone are likely to change significantly in the future with likely climate change. The zones of endemism located in relatively less damp, dry areas (dry zone) are predicted to have less risks from potential IAPS. However, projections indicate that the potential risks will likely increase in the future. South-west Wet Zone, Central Highlands, Northern Highlands, and Eastern Highlands zones of endemism are predicted to have high susceptibility to IAPS establishment where the majority of Lowland Rainforests is located.

4.2 Risks of IAPS on threatened endemic taxa

Potential risks of IAPS to threatened endemic taxa were evaluated based on suitability at occurrence points. The representation of reduced numbers of occurrences (~ 25%) in very high and high suitability classes and increased numbers (~ 75%) in moderate, low, and very low classes, compared to the current climate, signify the potentially decreased risks from IAPS to the threatened endemic taxa under the RCP 4.5 scenario. Similarly, under the RCP 8.5 scenario, representation of occurrences in the high suitability class was greater (>50) than the total of moderate, low, and very low classes, suggesting potentially increased risks. However, the analysis of occurrences of 11 individual taxa reveals that the risk from IAPS is not uniform among individual genera under climate change. Four taxa (*Adrorhizon, Davidsea, Diyaminauclea*, and *Hortonia*) are projected to have decreased risks in the future under both RCP scenarios; all other eight taxa are projected to have decreased risks under the RCP 4.5 scenario but increased risks under the RCP 8.5 scenario.

4.3 Risks of IAPS on forest-related ecosystems

Generally, all ecosystems are vulnerable to species invasions to a certain extent (McNeely et al. 2001). Our findings show that the risks from IAPS change remarkably between different ecosystems. Primarily, ecosystems located in the dry zone of the country are more susceptible to IAPS invasions under projected climate change models and thus the potential impact caused by these invasion dynamics could be severe. However, the reasons why some ecosystems are more vulnerable to species invasion needs better explanation (Dukes and Mooney 1999; Richardson et al. 2000). Invasive plants have the capacity to colonize easily in open areas, such as disturbed forest edges, as they are highly light-demanding (Daehler 2003). The dry zone ecosystem in Sri Lanka is relatively dry, less dense, heavily disturbed and plant diversity is comparatively low compared to the wet zone of the country. These conditions are, thus, likely to provide a conducive environment for IAPS to thrive (MoFE 1999; MOE 2012). It has been postulated that tropical forests are resistant to IAPS due to high species diversity and greater functional diversity (Fine 2002). Though such areas are climatically suitable for multiple IAPS establishment, the functional diversity attributed by high species richness in these tropical forests may not provide easy access for IAPS to establish and spread. In addition, native plants generally possess intrinsic resistance against the establishment of invasive plants (Standish, Robertson, and Williams 2001). Exotic invaders are often not strong enough to invade dense, leafy forest canopies since the established vegetation acts as a barrier against invasion (Thompson, Hodgson, and Rich 1995). Our findings also show that Lowland Wet Zone Rainforests, especially the Sinharaja rainforest, are climatically less suitable for IAPS invasion in the current climate even though the surrounding area is highly suitable for multiple IAPS establishment. Empirical studies verify that successionally advanced native forests support a lesser number of introduced plants and, in some cases, it is extremely rare to find exotics in such vegetation types (Rejmánek, Richardson, and Pyšek 2005). Invasion theories that focus on exotic plant invasions in specific ecosystems should be evaluated in order to achieve a better understanding of invasion dynamics under different climate change conditions.

4.4 Limitations of the study

Species' response to climate change can be idiosyncratic; the intensity of invasion and the potential consequences may vary depending upon the invasive taxa (Hejda, Pyšek, and Jarošík 2009; Bezeng et al. 2017). Risks posed by IAPS may not necessarily be directly proportional to the actual number of IAPS present e.g. native species in the low suitability class (1-2 IAPS) can carry more risks than those species in moderate suitability classes (3-5 IAPS); it seems to depend on the invasibility of species and their population sizes. We did not model the native biodiversity layer for 2050 on the assumption that climate change will not result in significant changes for native species in the next 30 years (by 2050). Generally, the majority of native plants do not have the capacity to change/evolve rapidly and spread fast (Ibanez et al. 2009; Davidson, Jennions, and Nicotra 2011) hence, it is unlikely to make a significant difference in the distribution of native plants by 2050. Moreover, we did not use long-term suitability predictions to hazard comparisons with present-day native flora. In view of this, we compared projected climatic suitability of IAPS by 2050 with current layers of biodiversity. Availability and accessibility of occurrence data are problematic in conservation science studies, particularly in developing countries (Kariyawasam, Kumar, and Ratnayake 2019b; Slodowicz et al. 2018). We believe that the subset of 423 occurrences of threatened endemic taxa used in this study is significant enough to arrive at a reasoned conclusion. However, we suggest further studies are required to examine all available occurrences and to generate more coherent inferences. Investigating the status and trends of potential risks to threatened endemic species is crucial to being able to take appropriate action to ensure the survival of existing species and for the restoration of declining populations. Despite some limitations, the predictive modelling approach provides a quantitative assessment of the risks posed by IAPS and such information can be used to formulate measures for the better conservation of biodiversity in Sri Lanka. Future results and recommendations can be refined and developed as more data become available.

5. Conclusion

Conservation and protection of unique and threatened endemic plant species, and their habitats, is crucial if their extinction is to be avoided in the not too distant future (MOE 2012). Assessment of the potential risks of IAPS in tropical islands is not easy; often due to a limited understanding of the issues involved and an inadequacy of quantitative ecological data to compare population sizes within different time frames. Predictive modelling studies and techniques are, thus, of great importance for assessing the potential risks posed by IAPS in light of the above limitations. Using Sri Lanka as a case study, our research provides demonstrable evidence of the potential risks of multiple IAPS invasions on native plant biodiversity in a tropical island setting and under projected climate change parameters. Primarily, the study reveals that the potential risks of IAPS to threatened endemic taxa and their habitats are projected to vary depending on how climate itself varies in the future. Furthermore, in the future, such risks may affect wet zone and dry zone flora of Sri Lanka differently. This may have implications for the conservation and sustainability of native flora and, thus, should be a major factor to consider in conservation planning and decision-making. Results of this study should provide an impetus for policy and decision-makers to improve their knowledge and understanding of where to focus their efforts for the future conservation of native plant biodiversity.

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