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Potential impact of climate change on the distribution of six invasive alien plants in Nepal

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ABSTRACT

The biological invasions have been increasing at multiple spatial scales and the management of invasive alien species is becoming more challenging due to confounding effects of climate change on the distribution of those species. Identification of climatically suitable areas for invasive alien species and their range under future climate change scenarios are essential for long-term management planning of these species. Using occurrence data of six of the most problematic invasive alien plants (IAPs) of Nepal (*Ageratum houstonianum* Mill., *Chromolaena odorata* (L.) R.M. King & H. Rob., *Hyptis suaveolens* (L.) Poit., *Lantana camara* L., *Mikania micrantha* Kunth, and *Parthenium hysterophorus* L.), we have predicted their climatically suitable areas across the country under the current and two future climate change scenarios (RCP 4.5 scenarios for 2050 and 2070). We have developed an ensemble of eight different species distribution modelling approaches to predict the location of climatically suitable areas. Under the current climatic condition, *P. hysterophorus* had the highest suitable area (18% of the total country's area) while it was the lowest for *M. micrantha* (12%). A predicted increase in the currently suitable areas ranges from 3% (*M. micrantha*) to 70% (*A. houstonianum*) with the mean value for all six species being 29% under the future climate change scenario for 2050. For four species (*A. houstonianum, C. odorata, H. suaveolens* and *L. camara*), additional areas at elevations higher than the current distribution will provide suitable habitat under the projected future climate. In conclusion, all six IAPs assessed are likely to invade additional areas in future due to climate change and these scenarios need to be considered while planning for IAPs management as well as climate change adaptation.

1. Introduction

Invasion by alien species and their subsequent negative impacts on biodiversity and ecosystem services namely on provisioning of resources, agriculture production, economy, and human health are critical components of human-mediated global environmental changes (Pyšek and Richardson, 2010; Matthews et al., 2017). Biological invasions are also considered to be one of the major drivers of biodiversity loss and species extinctions (McGeoch et al., 2010; Bellard et al., 2016). Impacts of biological invasions are often difficult to measure but they have been shown to be pervasive from the population to the community and ecosystem levels (Simberloff et al., 2013). A general estimate of economic losses and ecological damages caused by invasive species is measured in tens of billions of dollars per year (Pimentel et al., 2005) and the potential economic loss to global agriculture alone is worth several billions of dollar annually (Paini et al., 2016). The negative impacts posed by invasive species will be aggravated by climate change (Bellard et al., 2013) and the rapid surge in international trade and travel (Seebens et al., 2015). In addition to these negative impacts, benefits from biological invasions have been also perceived in the form of diverse ecosystem services (Shackleton and Shackleton, 2017; Vaz et al., 2017).

Significant efforts from the local to global scale have been made in research, assessment, and management of IAS. For example, the Inter-

Abbreviations: ANN, artificial neural network; AUC, area under curve; CTA, classification tree analysis; FDA, flexible discriminant analysis; GAM, general additive model; GBM, generalized boosting model; GCM, global circulation model; GLM, general linear model; IAPs, invasive alien plants; NAPA, national adaptation programme of action for climate change; RCP, representative concentration pathway; RF, random forest; ROC, receiver operating characteristic curve; SDM, species distribution modelling; TSS, true skill statistic

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Governmental Platform on Biodiversity and Ecosystem Services (IPBES) has identified biological invasions as one of the top priority areas for further research and assessment (IPBES, 2015). Likewise, Parties of the Convention on Biological Diversity (CBD) require action to be taken on preventing the further introduction and greater efforts to control or eradicate potential invasive species. One of the current strategic plans of the CBD is the 20 Aichi Biodiversity Targets, and the Target 9 of which includes the identification and prioritization of invasive species and their dispersal pathways as the priority actions to manage biological invasions by 2020 (CBD, 2010). Likewise, goal 15 (target 15.8) of the Sustainable Development Goals aims to introduce measures to prevent the introduction of invasive species and significantly reduce their impacts on terrestrial and aquatic ecosystems and control or eradicate the priority species by 2020 (https://sustainabledevelopment.un.org/sdg15). However, past efforts appear to have been inadequate as there is no clear downward trend in the rate of species introductions across geographic regions and within taxonomic groups (Seebens et al., 2017). While developed countries have formulated regulations for prevention, early detection and eradication, and management of invasive species such as the European Union's regulation (EU Regulation 1143/2014, http://ec.europa.eu/environment/nature/invasivealien/index_en.htm), several developing countries including Nepal are facing challenges to formulate relevant policies and programs (MFSC, 2014; McGeoch et al., 2016) due to lack of baseline data on species introduction across geographic regions and within taxonomic groups. Meanwhile, the invasion pressure in those countries is increasing making them further vulnerable to the biological invasions (Tittensor et al., 2014; Early et al., 2016).

Nepal is considered to be one of the countries with the greatest threat (ranked 3 out of 124 countries for the agriculture sector) from biological invasions (Paini et al., 2016). Located in the centre of the Himalayan biodiversity hotspot, Nepal has a large elevation gradient with extreme variations in topography and climate along that gradient. Due to the extreme climatic variation, ranging from tropical to alpine, introduced plant species native to any bioclimatic region can easily adapt to environmental conditions found in Nepal. Furthermore, the probability of introduction of alien plant species to Nepal appears high due to 1) increasing tourism activities particularly in mountain regions, 2) growing amount and diversity of imported agricultural products, 3) increasing quantity of imported crop seeds and other commodities, and 4) ineffective bio-security efforts including quarantine at international border points and airports. Currently, 179 species of flowering plants are known to be naturalized in Nepal (Shrestha et al., 2017a) and 26 of them are considered invasive (Shrestha et al., 2017b). Although the overall impact of biological invasions in Nepal has not been evaluated, the estimated annual cost of invasion to Nepal's agriculture sector alone is nearly US$ 22.7 million (Paini et al., 2016). Furthermore, the biological invasions have emerged as a significant threat to biodiversity and ecosystem services in Nepal and its severity and extent is consistently growing (MFSC, 2014).

In many ways, climate change and biological invasions have a synergistic impact, with climate change continuing to create new, suitable habitat for invasive species establishment, and therefore enhancing the invasion process (Bradley et al., 2009; Bellard et al., 2016). In comparison to native species, the invasive species are usually more abundant, tolerant to a broad range of climatic condition, and possess highly competitive biological traits hence they are more likely to adapt to new climate conditions (Hellmann et al., 2008). Therefore, in developing management strategies for invasive species, there needs to be a consideration of the climate change factors that can affect their distribution. Including climate change in management of invasive species helps to minimize the threat of these species in the future (Crossman et al., 2011). Furthermore, understanding the factors that affect the spread of invasive species and identifying their potential distribution are essential for controlling their further spread (With, 2002). Bioclimatic modelling tools provide quantitative scenarios of the effects of climate change on species distribution to support decision-making (Pereira et al., 2010). Species distribution modelling based on the geographical relationship between presence locations of species and climate conditions were used to predict potential distributions of invasive species (Bradley et al., 2009; Roura-Pascual et al., 2009; Villemant et al., 2011; Bellard et al., 2016). Although response of native species to climate change were studied at the minimum level in the Himalaya (Shrestha and Bawa, 2014; Ranjitkar et al., 2014; Aryal et al., 2016; Rana et al., 2017), knowledge on the response of invasive species to climate change is limited in the Nepal Himalaya. We predicted the potential response of the distribution of six highly problematic invasive alien plants (IAPs) to future climate change in Nepal and examine if their current potential elevation-range will shift with climate change. Few recent studies attempted to model the distribution of selected IAPs at the scale of the Himalaya and South Asian countries (Lamsal et al., 2018; Thapa et al., 2018). To our knowledge, this is the first analysis to model the current and future distribution of IAPs across Nepal.

2. Materials and methods

2.1. Species selection and occurrence data

The six most problematic IAPs (*Chromolaena odorata*, *Lantana camara*, *Mikania micrantha*, *Ageratum houstonianum*, *Hyptis suaveolens* and *Parthenium hysterophorus*) of Nepal (Table 1) were selected for modelling their distribution. The first three species are present in the list of 100 of the World's worst invasive species (Lowe et al., 2000) and the remaining three are emerging as highly problematic IAPs in Nepal due to their rapid expansion and negative impacts (Shrestha et al., 2015; Siwakoti et al., 2016). All these species are native to the tropical

Table 1
Characteristic features of the studied invasive alien plant species.

Scientific name (Family)	Common name	First year of report in Nepal	Seed dispersal mechanism	Mode of reproduction	Primary habitats invaded	Total occurrence points (used in modelling)
Ageratum houstonianum Mill. (Asteraceae)	Blue billygoat	1929	wind, water	Seed	Agroecosystem	1727 (816)
Chromolaena odorata (Spreng.) King & Robinson) (Asteraceae)	Siam weed	1825	Wind	Seed	Forests, shrublands	1355 (660)
Hyptis suaveolens (L.) Poit. (Lamiaceae)	Bush mint	1956	Water, wind, animals, humans and machinery	Seed	Shrublands, grasslands	589 (396)
Lantana camara L. (Verbenaceae)	Lantana	1848	Birds, mammals (fox and rodents)	Seed	Forests, shrublands	729 (438)
Mikania micrantha Kunth. (Asteraceae)	Mile-a-minute	1963	Wind, animals, water	Seed/vegetative	Shrublands, grasslands	344 (196)
Parthenium hysterophorus L. (Asteraceae)	Parthenium	1967	Wind, animals, water, vehicles, tools, machinery	Seed	Grasslands, agroecosystem	1021 (635)

Source: Tiwari et al. (2005); https://keys.lucidcentral.org/keys/v3/eafrinet/weeds/key/weeds/Media/Html/index.htm.

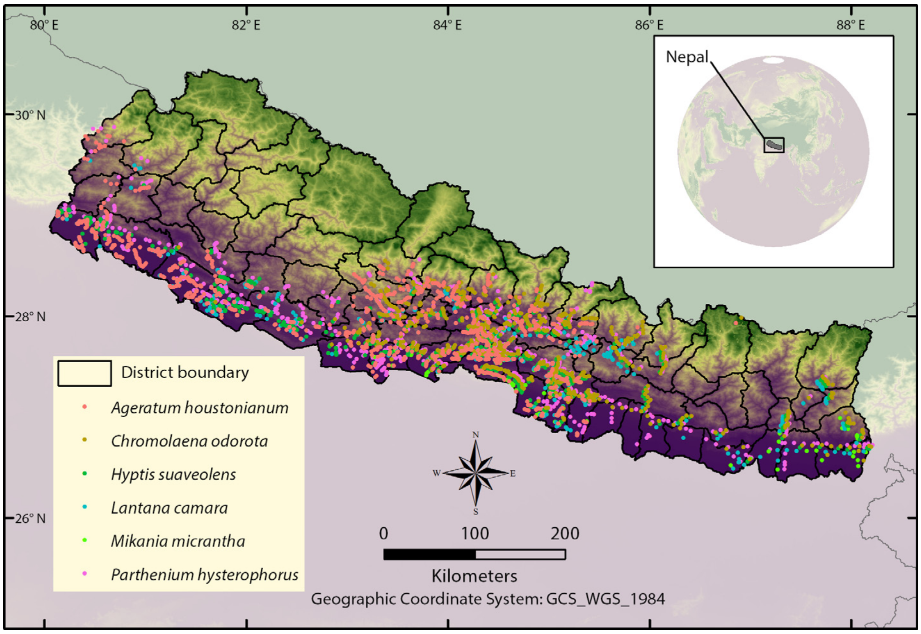

Fig. 1. Study area showing the occurrence of six invasive alien plant species in Nepal.

Americas and have been introduced to Nepal (Shrestha et al., 2017b). Local people considered three species (*A. houstonianum*, *M. micrantha*, *P. hysterophorus*) highly problematic and reported several negative impacts by these species on livelihoods and ecosystems such as reduction in agriculture production and forage supply, livestock poisoning, and adverse effects on forest regeneration (Shrestha et al., 2018a). The occurrence data of these IAPs (Fig. 1) were obtained from field surveys conducted in various localities of Nepal from 2013 to 2017 (Shrestha, 2014; Siwakoti et al., 2016; Shrestha et al., 2016; Shrestha et al., 2018b). There might be sampling biases in our location data, which may increase spatial auto-correlation of the localities. Spatial auto-correlation causes overfitting of models and spatial filtering of occurrence data can improve the model performance by reducing the auto-correlation (Boria et al., 2014). We applied spatial filtering by removing the multiple points located inside one-kilometer grid. The multiple presence points were removed to retain only one presence point per-grid of 30-arc-sec ($\sim 1 \times 1$ km) to correspond the spatial resolution of the environmental variables (Elith et al., 2010). For example, we used only 816 presence points out of 1727 for modelling distribution of *A. houstonianum*.

2.2. Environmental variables

Nineteen bioclimatic variables at 30-arc-sec resolution were obtained from WorldClim version 2 (http://worldclim.org/version2) (Fick and Hijmans, 2017). Multi-collinearity among environmental variables was tested using Pearson's correlation and variance inflation factors (VIFs). Only variables with a Pearson correlation > 0.80 and VIF > 5 were dropped as an indication that they had multicollinearity issue (Rogerson, 2001). The remaining eight bioclimatic variables: mean diurnal range [mean of monthly (max temp-min temp)], isothermality, mean temperature of driest quarter, precipitation of driest month, precipitation seasonality, precipitation of driest quarter, precipitation of warmest quarter, and elevation were used as predictors to model distributions of the species.

To observe the response of species to future climate, we used MIRCO5 (Model for Interdisciplinary Research on Climate), a global circulation model (GCM) submitted for Coupled Model Inter-comparison Project Phase 5 (CMIP5) (Watanabe et al., 2010). We downloaded MIRCO5 data for the Representative Concentration Pathways (RCP) 4.5 scenarios for two different periods (2050 and 2070) from the Climate Change, Agriculture and Food Security gateway (www.ccafs-climate.org) (Ramirez-Villegas and Jarvis, 2010). The MIROC5 is considered as a consistent GCM for rainfall simulation projection in the Indian subcontinent (Babar et al., 2015). It represents a better seasonal cycle of monsoonal precipitation (Ul Hasson et al., 2016) and simulates extreme as well as summer precipitation better than other GCMs for the South Asian region (Mishra et al., 2014). RCP 4.5 represents a target forcing of 4.5 W/m^2 above the pre-industrial baseline by 2100 with stabilization after that date by the employment of a range of technologies and strategies for reducing greenhouse gas emissions (Clarke et al., 2007). We assume that a medium stabilization or intermediate scenario, the RCP 4.5, is a reasonable carbon emission scenario. In this scenario, the predicted global temperature increase is 1.8 ± 0.5 °C by 2100 with maximum increases expected over land (2.4 ± 0.6 °C) than oceans (1.5 ± 0.4 °C) (Collins et al., 2013).

2.3. Species distribution modelling

Several species distribution algorithms for species distribution modelling are available and performances of the algorithms vary significantly (Elith et al., 2010). As a single modelling algorithm does not provide the best predictive accuracy, an ensemble of multiple algorithms is considered to produce better accuracy (Araújo and New, 2007; Thuiller et al., 2009). We used BIOMOD2 package (Thuiller et al., 2009) in R-CRAN 2.15.1 (R Development Core Team, 2015) to create an ensemble of eight algorithms available in the BIOMOD2 package. The eight algorithms were three regression methods (GAM: general additive model, GLM: general linear model, MARS: multivariate adaptive regession splines), three machine learning methods (ANN: artificial neural network, GBM: generalised boosting model, RF: random forest), and two classification methods (CTA: classification tree analysis, FDA: flexible discriminant analysis). Following Barbet-Massin et al. (2012), we used 2000 pseudo-absences selected randomly outside a buffer of 10 km from the presence points. The pseudo-absence generation was repeated three times per species to avoid random bias and equal weight was given for presences and pseudo-absences. We have 72 model runs for each species (eight models, three evaluation runs, and three pseudo-absence selection procedures). The presence and pseudo-absence data were split into two subsets: 70% used for training the models while 30%

used for evaluating the predictive power of each model (Araújo et al., 2005). We evaluate the predictive performance of the models using the true skill statistic (TSS) as it is independent of prevalence—the ratio of presence to pseudo-absence data in the presence-absence predictions (Allouche et al., 2006). TSS accounts for both sensitivity and specificity and its values range from −1 to +1, where +1 indicates perfect agreement, and scores range from 0.7 to 0.9 specifies fair to good model performance (Allouche et al., 2006; Li et al., 2016). As there is no specific guideline for TSS (Gallien et al., 2012), we choose models with TSS score > 0.60 to build an ensemble from the projection outputs of the eight algorithms by using a weighted mean approach that weights each model outputs according to predictive performance (TSS score) (Marmion et al., 2009). We also observed Area Under the ROC curve (AUC) and Cohen's Kappa statistic scores to complement the evaluation of the predictive preformation of our models. The probabilistic prediction of the ensemble was converted to binary presence-absence map based on a threshold that maximizes TSS score (Liu et al., 2013). To assess the potential change in the distribution, we compared projection maps produced by SDM under current and future climate for each species.

3. Results

The extent of climatically suitable habitats was modelled to show the distribution of six invasive alien plants (IAPs) under current and future climate change scenarios (Fig. 2). Under the current climatic condition, *Parthenium hysterophorus* had the highest suitable area climatically while *Mikania micrantha* had the least (Table 2).

Currently, 64 out of 75 districts of Nepal had suitable habitat for at least one out of six IAPs studied; 18 districts had all six species; 19, 18, six and two districts had five, four, three, and two IAPs, respectively. Rukum was the only district that had climatically suitable habitat for a single species (*P. hysterophorus*). *Lantana camara* was the most widespread IAP and its suitable habitats extended across 62 out of 75 districts of Nepal whereas suitable habitats of *M. micrantha* confined only in 35 districts (Table 3). Under the current climatic condition, the majority of IAPs (> 50% species) lied in tropical and sub-tropical regions ranging from 100 to 2100 m elevation. Similarly, the central region of Nepal was the hotspot for the IAPs with the most extensive areas of climatically suitable habitats for all the studied species.

The predicted climatically suitable areas for all the six IAPs under the RCP 4.5 climate change scenario would expand across Nepal for 2050 and further expansion was anticipated for 2070 (Fig. 3). The maximum increase (+70%) in the suitable habitat was predicted for *Ageratum houstonianum* followed by *Hyptis suaveolens* (+66%) and *M. micrantha* (+14%) for the period 2050 with respect to current climate while the minimum increases in suitable habitats were predicted for *P. hysterophorus* (+3%), *L. camara* (+10%) and *Chromolaena odorata* (+12%). Although the trend of expansion of climatically suitable areas was consistent for 2070, the rate and extent varied among species. The suitable areas for *H. suaveolens* would be almost double (+95%) for 2070 with respect to current climatic condition followed by *A. houstonianum* (+83%) and *C. odorata* (+20%). The rate of increase slowed down for all species from 2050 to 2070 and a small decrease in the suitable areas of *L. camara* from 2050 to 2070 was predicted.

With climate change, more suitable areas for the IAPs would be created primarily in subtropical and temperate regions of the central Nepal. Physiographically, a major increase in the suitable areas of IAPs were seen in the Middle Mountain and High Mountain out of the five physiographic zones of Nepal (Tarai, Siwalik, Middle Mountain, High Mountain and High Himal). Currently, Tarai, Siwalik and Middle Mountain have higher suitable areas for the IAPs than the High Mountains. The district wise suitability increased from 64 to 67 districts for 2050 and remained static in 2070. However, the extent of the suitable areas within the district would worsen in 2070. Currently, the number of the district with climatically suitable areas for all six species was only 18, which would be increased to 28 in 2050 and 32 in 2070. A clear shift towards higher elevations in the suitable areas for IAPs was predicted in future with respect to current climate (Fig. 4). The common elevational range in the predicted suitable areas for three species (*A. houstonianum*, *L. camara*, *P. hysterophorus*) ranged from 100 to 2,100 m with the highest elevational range of 2500 m for *A. houstonianum*. Shifts in this common elevational range for three species from 100–2100 m to 100–2300 m and 100–2400 m were observed in 2050 and 2070, respectively. Similar shifts in the maximum elevation range of the currently suitable areas of *A. houstonianum* were noticed from 2500 m in current climatic condition to 3200 m in 2050 and 3300 m in 2070.

The model performance evaluated by different performance matrices scores are given in Table 4. The AUC values ranged from 0.84 to 0.93, TSS between 0.55 and 0.78, and the Kappa between 0.44 and 0.85. *A. houstonianum* showed good or excellent evaluation while rest of the other species demonstrated good and fair evaluations.

4. Discussion

This study for the first time showed the potential impact of future climate on the distribution of the six most problematic invasive alien plants (IAPs) in Nepal. Given that, the climate change has affected the distribution of invasive species causing expansions in climatically suitable habitats worldwide (Bellard et al., 2013), our study shows that future climate change will cause similar increase in the climatically suitable areas of IAPs in Nepal. Several Global Circulation Models (GCMs) seem to agree that Nepal will likely to become warmer and wetter in future; the average annual temperatures will increase by 3.0–6.3 °C (mean 4.7 °C) and monsoon rainfall is likely to increase by the 2090s (NCVST, 2009). Our projections show the areas of climate suitability for six IAPs to increase in future. The predicted maps provided by this study will be helpful for prevention and early detection of the IAPs in the new areas. For example, we did not have occurrence data from Rukum district for modelling but our model predicted suitable areas for *Parthenium hysterophorus*. Interestingly, a recent visit (12 October 2017) by one of the authors (B.B. Shrestha) revealed the occurrence of two small populations of *P. hysterophorus* in Rukum district. Our result of an increase in suitable areas also corresponds with the predicted suitable habitat of *P. hysterophorus* by Mainali et al. (2015). They reported a large extent of Asia including Nepal would be highly suitable for *P. hysterophorus* in future.

It is important to note that the species such as *Ageratum houstonianum* and *Hyptis suaveolens*, which have less suitable areas under current climate, will expand rapidly with climate change in future. Since *A. houstonianum* has been reported by local communities as the most problematic IAPs in agroecosystems of Nepal (Shrestha et al., 2018a), predicted rapid expansion of this species in future will have significant negative impacts to agriculture production. Therefore, high priority be given to species like *A. houstonianum* for management to reduce their current and future damages. Additional areas at high elevation will be suitable for most of the IAPs assessed in this study. Based on the historical occurrence information, an upward migration of five IAPs including *A. houstonianum* to mountain regions by > 800 m in the last 20 years has also been reported (Siwakoti et al., 2016). MaxEnt modelling of eleven IAPs (including three species considered in the present study – *A. houstonianum*, *L. camara* and *P. hysterophorus*) in Kailash Sacred Landscape of Western Himalaya has also predicted the expansion of suitable areas under future climate scenarios (RCP 2.6 and 8.5) (Thapa et al., 2018). Therefore, collectively a larger area will be suitable for IAPs thus increases the risk of future invasion in Himalaya. Furthermore, the severity of the invasions will increase in future with the increase in the number of districts that provide suitable areas for additional IAPs. Spatially, new suitable areas for IAPs will be created in the temperate Middle Mountain regions—the regions with a higher number of species and ecosystem diversity (Vetaas and Grytnes, 2002)

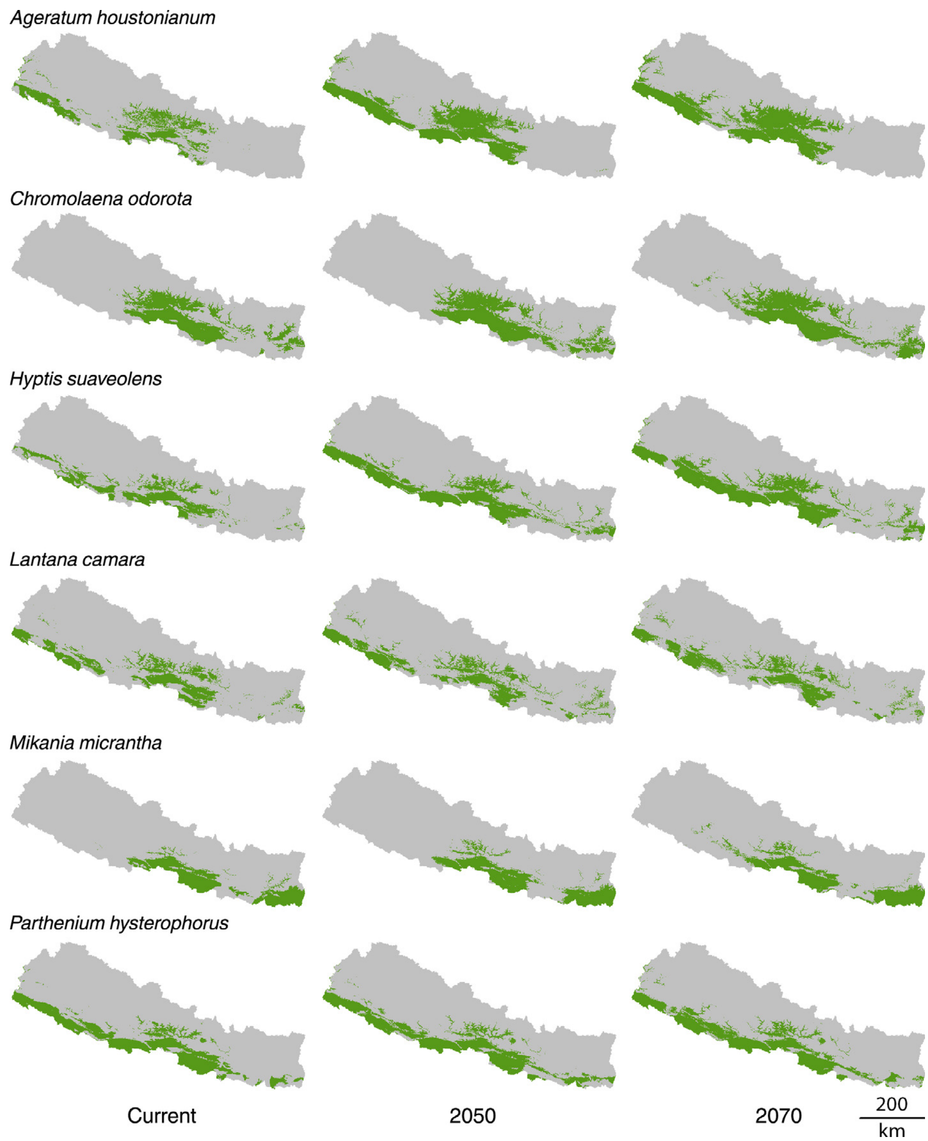

Fig. 2. Changes in the current habitat suitability of six invasive alien plants in Nepal with future climate (green regions represent the predicted suitable areas of each species). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Current suitable areas of the six invasive alien plants.

Name of species	Suitable area (km^2)	Percentage (%) of Nepal's area
Ageratum houstonianum	17,169	13
Chromolaena odorata	21,645	16
Hyptis suaveolens	16,003	12
Lantana camara	18,967	14
Mikania micrantha	15,837	12
Parthenium hysterophorus	24,735	18

Table 3
Number of districts in Nepal with the suitable areas for the six invasive alien plants modelled under current and future climate.

Species	Climatic conditions		
	Current	2050	2070
Ageratum houstonianum	47	47	48
Chromolaena odorata	50	47	54
Hyptis suaveolens	50	60	63
Lantana camara	62	68	65
Mikania micrantha	35	44	48
Parthenium hysterophorus	54	59	55

as compared to other regions. The Middle Mountain region also has a higher number of community-managed forests—the major conservation and livelihood intervention project in Nepal (Shrestha et al., 2010). Although the response of species to climate change may be region specific (Petitpierre et al., 2016), climate change induced upward migration of invasive species is a global phenomenon (Pauchard et al., 2016). In addition to climate change, upward migration of invasive species is also facilitated by infrastructure development (e.g. road, tourist facilities) and increasing anthropogenic disturbances in the mountain regions. Identification of potentially suitable regions for IAPs provides an opportunity for their prevention in mountains where control is more challenging than in surrounding lowland areas (McDougall et al., 2011; Pauchard et al., 2016). Prevention of the spread of IAPs to mountains requires the identification and monitoring of species-specific dispersal pathways, and establishment of the mechanism for early detection and eradication.

Although this study provides critical information on the climatically suitable habitats in current and future climate, our models are based on only abiotic variables disregarding dispersal capacities, biotic

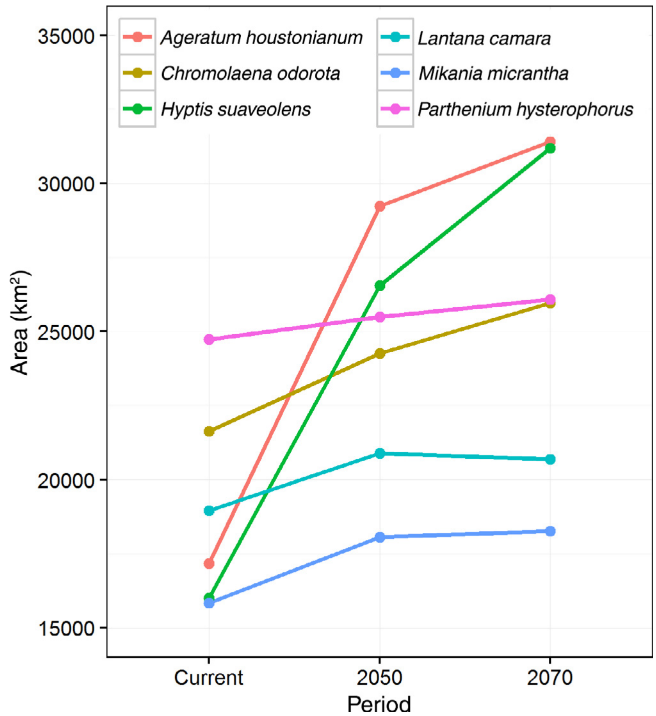

Fig. 3. Changes in the suitable habitats of six invasive alien plants in Nepal under future climate.

interactions such as facilitation and competition, and vectors of invasive species as noted by Gaston and Fuller (2009). Suitable climatic conditions do not automatically lead to the successful establishment for new species; they must overcome geographic barriers to travel to new locations, survive, and tolerate with biotic conditions and non-climatic environmental factors at the arrival site (Bellard et al., 2013). As in most of the species distribution modellings (SDMs), this study lacks that information on dispersal capacities and biotic interactions. The SDMs also assume that point locations represent a condition of environmental equilibrium for a species. Nevertheless, the results can provide information for guiding IAPs management by identifying regions potential to invade that can be included in risk assessment process and their proactive management. Therefore, this preliminary understanding of current and future distribution of invasive species is helpful to make management plans and policy to manage them.

The selection of models using AUC scores is popular among SDM studies, however, usage of AUC scores for model selection is heavily criticized (Allouche et al., 2006). AUC scores may be misleading if used as a sole criterion for choosing a model (Mainali et al., 2015). We used multiple matrixes (AUC, TSS and Kappa) to evaluate our models and used TSS score to build an ensemble from the projection outputs of the eight algorithms by using a weighted mean approach that weights each model outputs according to predictive performance. Based on the index for classifying model prediction accuracy (Thuiller et al., 2010), the average AUC scores of out models ranged from 0.84 to 0.93 indicates good to excellent accuracy and the average Kappa scores between 0.44 and 0.85 signifies fair to excellent accuracy.

Climate change has already impacted the distribution of some native species in Nepal and contraction in the suitable habitats for native species under future climate was predicted (Aryal et al., 2016). Our results of the expansion of climatically suitable areas for IAPs added collective pressure to native species. Invasion threat and rapid expansion of IAPs such as *Mikania micrantha*, *Ageratina adenophora*, *Chromolaena odorata* and *Lantana camara* were realized in the national policy documents (e.g., MFSC, 2014). National Adaptation Programme of Action for Climate Change (NAPA) of Nepal emphasized on research to control invasive species (MoE, 2010). Yet, there has been no systematic study to map the distribution of invasive species in Nepal. Furthermore, National Biodiversity Strategy and Action Plan (MFSC, 2014), NAPA and other national level conservation and climate change policies failed to account the cascading threats posed by IAPs with climate change as the scientific studies to provide the basis for such policies were lacking. By mapping the current and future suitable areas for six IAPs, this study provides a preliminary understanding of the potential impacts of climate change on the distribution of the most problematic IAPs in Nepal. Taking accounts with the aforementioned limitations, the results can be combined with extensive field surveys and community reporting to support the management efforts and conservation planning. Hence, the results have a clear policy implication.

Along with climate change, several changes such as a rapid change in land use and land cover including construction of roads, prolific growth in foreign trade, and consistent increase of labour migration, and booming tourism industry are undergone in Nepal (Ghimire, 2016; MCTCA, 2016; MLE, 2016; Paudel et al., 2016). International trade, labour migration, and tourism facilitate greater human mobility, which directly and indirectly help to spread invasive species (Pyšek and Richardson, 2010). Short generation times, greater environmental tolerances, high fecundity, and strong dispersal ability make invasive species well suited to change (Bradley et al., 2009). Likewise, the trade of ornamental plants and seeds facilitate biological invasions (Pyšek and Richardson, 2010). Therefore, the invasion risk in Nepal has reached a higher level. The situation may worsen with future climate change. Although this study focuses only on the impact of future climate change on the distribution of IAPs, management efforts of IAPs should account these factors of global change that have direct and immediate effects on the distribution of IAPs.

Although this study provides some useful insights into the distribution of six important IAPs of Nepal under the current and future climates, there are a further 20 IAPs reported in Nepal (Shrestha et al., 2017b). The current distribution of the majority of IAPs is still not known. Although the threats and negative impacts of invasive species were anticipated (MFSC, 2014), scientific studies at a scale helpful to make management plans for IAPs are warranted. Furthermore, studies to map the distribution of remaining IAPs as well as to understand how they affect native plants, protected areas, forests and other ecosystems is necessary to formulate management plans and policies for the IAPs to a country that is highly vulnerable to biological invasion.

5. Conclusion

Although the management of invasive species is an essential component of biodiversity conservation and natural resource management, it is a complex and challenging issue. The challenge of the management has been augmented as biological invasions are exacerbated by the increasing global trade, human mobility, and unprecedented climate change. Our study shows that the future climate change will likely to create additional suitable areas for the selected IAPs in Nepal. Increasing climatically suitable areas for IAPs in future will facilitate their further spread, which have already been causing negative impacts on the livelihoods, economy and biodiversity in Nepal. The results of this study can be used as a cautionary note for the management of IAPs and conservation of biodiversity in future. Our study reaffirms the necessity of including the potential worsening effects of climate change while devising management policy and plan to control and eradicate IAPs in Nepal.

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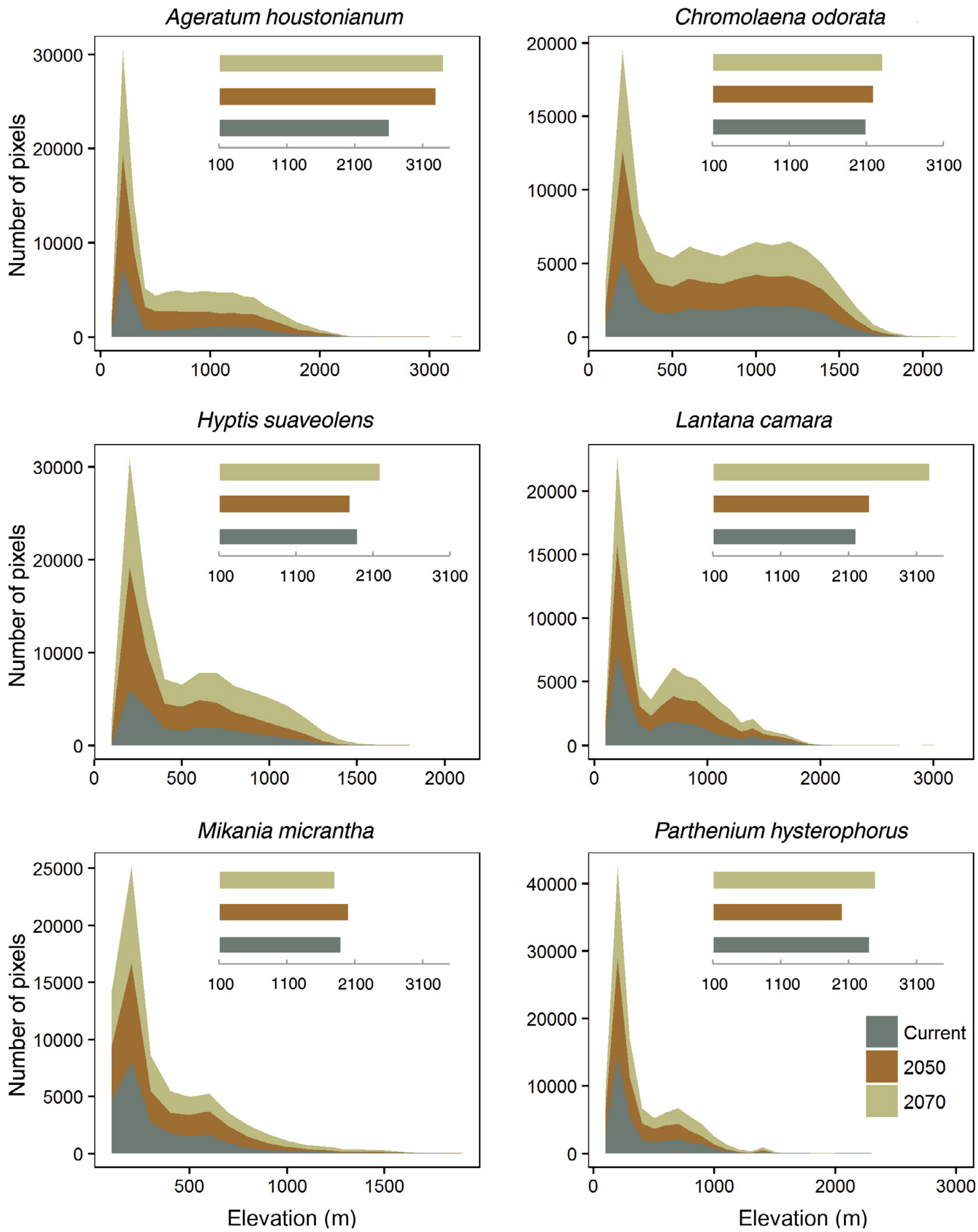

Fig. 4. Changes in the extent of suitable areas (measured as the number of pixels) and in the elevation range (shown in the bar) of six invasive alien plants in current and future climatic conditions in Nepal.

Table 4
Performance of the models under different evaluation statistic. The average value of 72 different runs under current climate are reported.

Species	Evaluator		
	TSS	Kappa	AUC
Ageratum houstonianum	0.65 ± 0.03	0.85 ± 0.03	0.88 ± 0.02
Chromolaena odorata	0.69 ± 0.04	0.62 ± 0.04	0.90 ± 0.02
Hyptis suaveolens	0.63 ± 0.03	0.48 ± 0.05	0.86 ± 0.02
Lantana camara	0.55 ± 0.03	0.44 ± 0.06	0.84 ± 0.03
Mikania micrantha	0.78 ± 0.05	0.58 ± 0.07	0.93 ± 0.03
Parthenium hysterophorus	0.60 ± 0.03	0.51 ± 0.03	0.86 ± 0.03

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