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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.

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