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Will *Ethulia gracilis* Del Become Invasive in India? An Analysis Using Ecological Niche Modelling Approach

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ABSTRACT

In the era of Anthropocene, an ability to predict the rate at which an alien invasive species spreads its range in a new habitat in response to climate change is of growing importance. The ability of modelling tools to predict the potential areas of spread can help in prioritizing for effective management of invasive species. Further, the methods used for modelling range spread of an alien invasive species can also be employed to assess the distributional implications of the species in response to climate change. An exotic weed *Ethulia gracilis* (Family Asteraceae), was recently found for the first time in India growing along the road side and in fallow lands. This raised serious issue of concern as the species can invade rapidly. In this study, we identified potential habitats of the species & areas where the species can invade both under current and future climate scenarios using ecological niche model. Our study highlights that climate change can accelerate the potential spread of the species in future.

Key words: Niche modelling, Invasion, Climate change, Species introduction, Asteraceae

INTRODUCTION

Besides anthropogenic activities, one of the greatest threats to native biodiversity, agriculture, livelihoods, health and forestry is alien invasive species (MEA 2005). The rapid increase in trade and human movement has accelerated the rate of introductions (Mack et al. 2010). Climate change on the other hand, is another important factor that accelerates the spread of invasive species and cause severe impact on the economy, health, biodiversity and the ecosystem (Bradley et al. 2010, Uma Shaanker et al. 2010). Identifying the current and future risk areas susceptible to invasion is of greater importance to develop sound, scientific policies in place to effectively manage the spread of invasive species.

Ethulia gracilis belongs to family Asteraceae was recorded for the first time in Belagavi district in Karnataka in 2018 (Dalavi et al. 2018). Usually, the process of alien species invasion involves three steps: transport of species into new location, establishment in the newer location and then subsequent spread across the new landscape (Elton 1958, Nobin and Ravikanth 2020). It is important to understand how far and how quickly the alien invasive species *Ethulia gracilis* will spread (Hulme 2003). The species has potential to become an invasive weed in the cultivated fields, fallow lands and other disturbed areas. Ever since its discovery in India, this exotic weed has raised a serious concern as like other Asteraceae members such as *Parthenium hysterophorus*, *Chromolaena odorata*, and so on, it can freely interbreed and produce innumerable viable seeds in a single generation (Dalavi et al. 2018). It is important to note that *E. gracilis* is recently been spotted in India and there has been no detailed studies to assess the species' impact. According to the Kew, this species is "weed of roadsides, cultivated ground, dry open places; ± 1230 m" in introduced range (Roskov 2018). Hence, given this background, it is important to see if this species is likely to become invasive (or spread) in India. It is also important to identify possible niches that are suitable for this species in the future as it might become invasive. Invasive species is a species which essentially shifting its range in response to climate change (Parmesan 2006).

In this study, we try to address three major questions. Where is the species currently distributed? Where will the species spread in the near future? And finally how quickly will the species spread? We assess the susceptible areas for *E. gracilis* colonisation under present and future climate change scenarios using ecological niche models (ENM). The ENM considers presence only occurrence records and using a suite of ecological variables, identifies potential habitat of a species (Yackulic et al. 2013). The ENM is widely used in predicting the potential distribution of invasive species spread, which can be helpful in the management of the species (Jimenez-Valverde et al. 2013). Our study also tries to: 1) map the potential areas that are susceptible to invasion by *E. gracilis* under the present climate and future climate scenarios, and 2) identify the bio-climatic factors suitable for invasion of *E. gracilis*. Based on the results of our study, we propose management options for a potential invasive species in India.

MATERIALS AND METHODS

The occurrence records for *E. gracilis* was downloaded from Global Biodiversity Information Facility (GBIF, http://www.gbif.org, accessed as on 12-April-2021) for Native region (Africa), from Dalavi (2018) for India and Global Biodiversity Information Facility (GBIF 2021) for Ethiopia. Spatial thinning of occurrence records was done to remove auto-correlation and reduce sampling bias (Aiello-Lammens et al. 2015). Finally, we used nine records for niche modelling. For ENM, we used a total of 19 Bioclimatic variables (ver 2; http://www.worldclim.org) and altitude (www.earthexplorer.org) with spatial resolution of 30 seconds (~1km^2). We used present bioclimatic variables (average for 1960-1990) and future i.e., 2070 (average for 2061-2080). The future bioclimatic dataset was selected as per recommendations from Intergovernmental Panel on Climate Change (IPCC) data in its fifth Assessment Report (AR5) (Moss et al. 2010) developed by Global Circulation Model (GCM) HADGEM2-AO (Hadley Global Environment Model 2 - Earth System) for two different scenarios i.e., Representative Concentration Pathway (RCP's) 2.6 and 8.5 (Baek et al. 2013). The RCP's are representations of possible changes in future anthropogenic greenhouse concentrations. We selected HADGEM version 2 because it has greater improvements in data when compared to other version's enabling better predictions (Martin et al. 2011). The environmental covariates were refined by removing highly correlated covariates $|r^2| > 0.70$ using Pearson's correlation coefficient (Dormann et al. 2013). The final set of variables used for species distribution modelling are as follows: Altitude, Bio1, Bio2, Bio3, Bio6, Bio12, Bio14 and Bio15.

For ENM, we used Maximum Entropy algorithm V. 3.4.1 (Phillips et al. 2006) as it is widely used in variety of studies such as planning conservation studies, mapping potential invasion risk for various taxa's and in disease spread prediction (Sarma et al. 2015, Priti et al. 2016, Yi et al. 2016, Ahamed et al. 2019). The detailed method used in MaxEnt modelling is given elsewhere (Sarma et al. 2015, Ahamed et al. 2019). We ran MaxEnt model for two datasets, a) for global data (both native and introduced) and b) only for native data points and projected to India (See Fitzpatrick and Weltzin 2005, Barbosa et al. 2017). This approach was employed because modelling species distribution based only on native ranges is likely to underestimate areas suitable for invasion (Fitzpatrick and Weltzin 2005). We categorised the final model to; Low risk (0.0–0.25) color-coded as blue, moderate risk (0.25–0.50) color-coded as white, High risk (0.50–0.75) color-coded as light red and high risk (0.75–1.00) color-coded as red (Sarma et al. 2015). Using DIVA-GIS (Hijmans et al. 2005), we calculated the frequency of the pixel for each category and multiplied by resolution of pixel (1 km^2) to assess the change in area by simple differencing.

Model evaluation

The MaxEnt model was evaluated by Area under Receiver Operating Curve (ROC) popularly known as AUC by subsampling 20% of the occurrence records for testing and 80% of the records for training. The AUC values vary from 0-1 where the values < 0.5 signifies that the model is worse than random, 0.5 – 0.7 signifies poor accuracy, 0.7 – 0.9 signifies moderate accuracy and > 0.9 signifies high accuracy (Swets et al. 1988).

Range change analysis

We analysed the suitable habitat change for the future scenario i.e., 2070 (average for 2061–2080) for Representation Concentration Pathways (RCPs) 2.6, and 8.5. We calculated the frequency of the pixel for each category and multiplied by resolution of pixel to assess the change in area by simple differencing.

RESULTS

Model performance

The evaluation of MaxEnt prediction indicated a good fit with mean AUC Train of 0.976 for native only occurrences and AUC Train of 0.969 for combined occurrences. The analysis of variable importance using jack-knife methods suggests that Temperature seasonality (Bio4), Annual mean temperature (Bio1) and Precipitation of warmest quarter (Bio18) had contribution of 35.1%, 31.8% and 15.8% (total of 82.7 %) in case of predictions using native occurrences and in case of prediction's using combined occurrences is 39.1%, 25.5% and 18.6% (Fig. 1). In general, Bio4, Bio1 and Bio18 have significant influence on the distribution of *E. gracilis*. The top three variables in both cases i.e., models developed using native and combined occurrences remain same however, percentage of contribution in variables show slight variations.

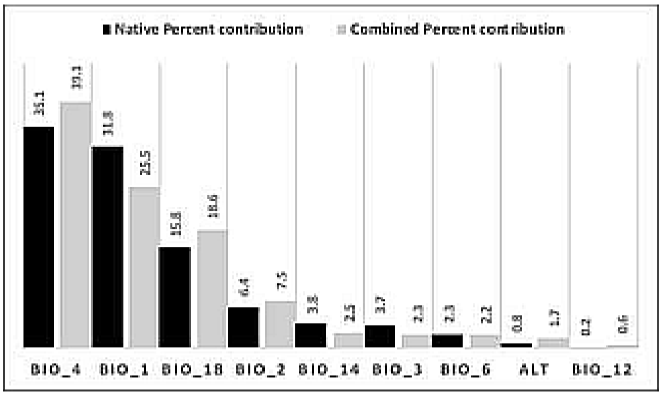

Figure 1. Jackknife analysis of variable importance for different variables used in ENM analysis

Extent of distribution

The MaxEnt model using native occurrences predicts Karnataka, Tamil Nadu, Goa and southern parts of Maharashtra to be moderately suitable. MaxEnt model using combined occurrences (global dataset) predicts Northern parts of the Western Ghats in Karnataka, Southern parts of Maharashtra as high-risk regions whereas, rest of the regions across Goa, Karnataka, Tamil Nadu and Southern parts of the Maharashtra are moderately risk areas (Fig. 2). The MaxEnt prediction for the future using native occurrences indicates that Northern Western Ghats in Maharashtra and Karnataka, Goa, northern western Karnataka and Western Tamil Nadu are high risk areas. In case of predictions using combined occurrences, MaxEnt predicts that Northern Western Ghats in Maharashtra, Karnataka and Goa are very high-risk areas. Gujarat, Western Tamil Nadu and Karnataka are moderate risk areas. Andhra Pradesh falls under low risk areas (Fig. 2).

Area change analysis

Range contraction and expansion analysis using native occurrence data indicates that the low risk areas decrease from 38,04,022 to 35,55,505 km^2 when compared to current and future scenarios. The moderate risk area increase from 3,58,606 to 4,71,138 km^2 the high-risk areas increase from 14,611 to 1,47,001 km^2 and very high-risk increase from 0.0 to 3,595 km^2 (Table 1). For combined occurrences, the low risk areas decrease from 38,48,821 to 36,03,297 km^2 when compared to current and future scenarios. The moderate risk area increase from 3,07,139 to 4,81,860 km^2 the high-risk areas increase from 21,276 to 71,974 km^2 and very high-risk increase from 3.0 to 20,108 km^2 (Table 1).

DISCUSSION

Where is the species currently distributed?

The *E. gracilis* is native to Africa and was first spotted in Karnataka which warrants this study to understand if this species will become established in India. We studied the potential distribution of *E.gracilis* under current and future climate change scenario to assess if this species has a potential to become invasive in India and to identify the most vulnerable areas for invasion. The MaxEnt model using native occurrences predicts Karnataka, Tamil Nadu, Goa and southern parts of Maharashtra to be

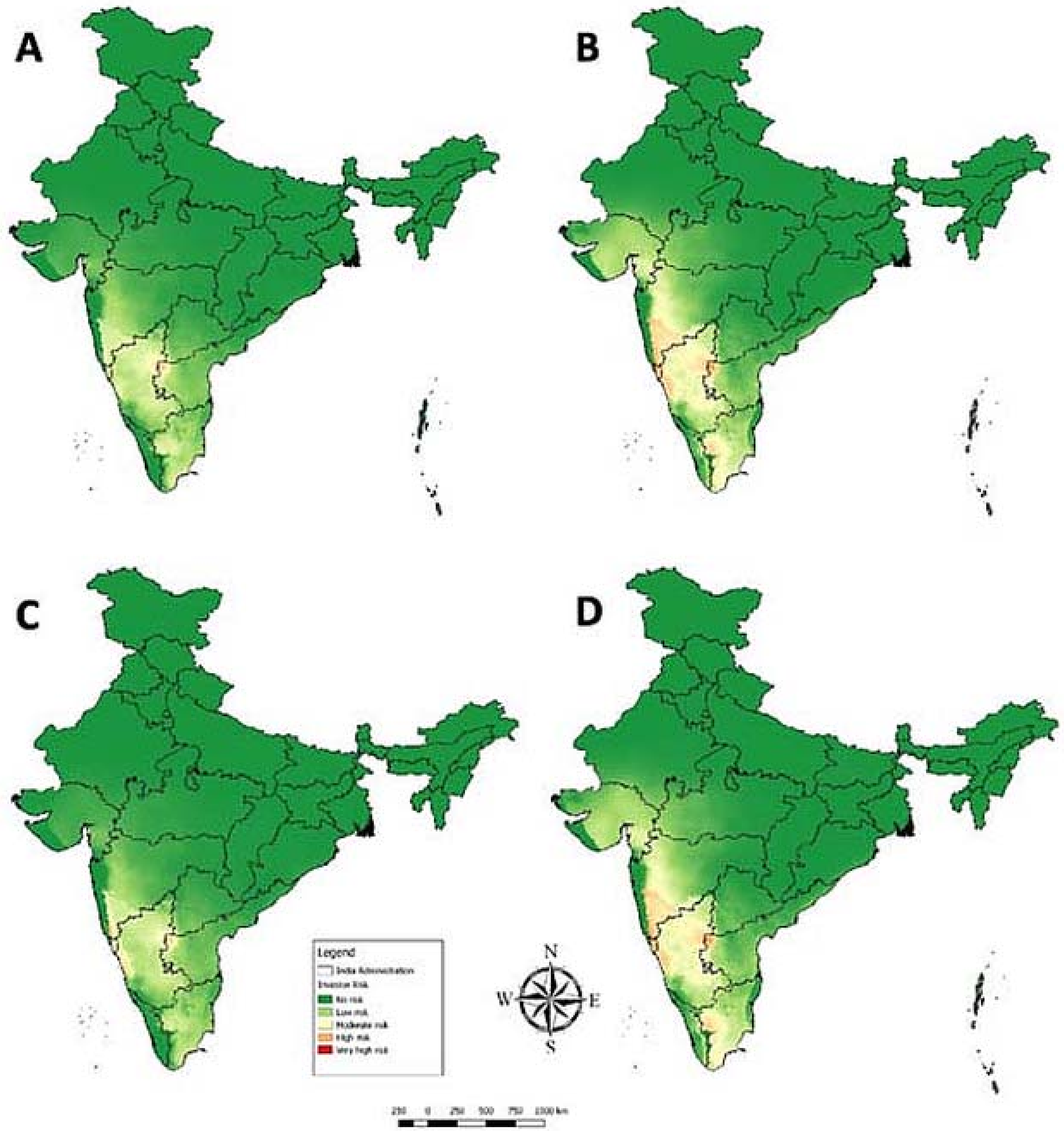

Figure 2. MaxEnt results depicting suitable habitats under current and future scenario (RCP 8.5-2070). A) MaxEnt model for current scenario using Native points, B) MaxEnt model for future scenario using Native points, C) MaxEnt model for current scenario using both Native & alien points, D) MaxEnt model for Future scenario (RCP 8.5) for both Native & Alien points.

Table 1. Analysis of area change between current and future climate for *E. gracilis* in India.

Range	**Description**	**Native Occurrences**		**Combined Occurrences**	
		Current	**RCP 8.5**	**Current**	**RCP 8.5**
0.00 - 0.25	Low Risk	38,04,022.00	35,55,505.00	38,48,821.00	36,03,297.00
0.25 - 0.50	Moderate Risk	3,58,606.00	4,71,138.00	3,07,139.00	4,81,860.00
0.50 - 0.75	High Risk	14,611.00	1,47,001.00	21,276.00	71,974.00
0.75 - 1.00	Very High Risk	-	3,595.00	3.00	20,108.00

moderately suitable habitats. The only report available till date is of the species being sighted in Belagavi district in Karnataka.

Where will it spread in the near future? Predicting the potential range of *E. gracilis* in India

Once the present range of a newly spotted alien invasive species has been described (Dalavi et al. 2018), the next important question is whether there is a potential of that species to spread further? The model predicted significant areas of Karnataka, Goa, Maharashtra, Tamil Nadu and Andhra Pradesh as vulnerable for the invasion in the current scenario. On the other hand the Western Ghats, which is one of the hotspot of biodiversity is also vulnerable for invasion (Fig. 1). Our ENM analysis suggests that climate change would increase the habitats suitable for *E. gracilis* in India. There would be an expansion of moderate and high suitable areas whilst, the low risk areas would decrease in future. The range-prediction techniques used in this study is of course, inadequate when applied in isolation to describe or predict the potential range of a *E. gracilis* in India. However, the use datasets on current distribution as well as spatial datasets on climate, topography and other important environmental features can help to make useful predictions of the potential distribution of the species. The analysis of area change between current and future shows that there is significant decrease in low risk areas while on the other hand, there is a significant increase in moderate risk and high risk areas in future. Our findings are in agreement with several other studies on other closely related species (Roura-Pascual et al. 2005, Wei et al. 2017).

Would climate change help the species spread in India?

The results of ENM suggests that most of the invasion risk are in the regions with warm temperature. In our analysis, both in current and future scenarios, temperature is the most influencing factor (Bio4 and Bio1) whereas, influence of precipitation is comparatively less. The development of sound management policies play vital role in the management of invasive species. The climate change can have profound effect on the species spread hence, sound scientific management should be identified to mitigate the spread of the invasive to prevent adverse effects on native biodiversity, economics and health of ecosystem.

Our analysis suggest that the *E. gracilis* has a potential to become invasive or at least attain pest status in Peninsular India. Even though the invasion risk areas are at moderate risk, the introduced plants do show niche shift in the novel environment (Atwater et al. 2018, Ahamed et al. 2019).The congener, *Ethulia conyzoides* is highly invasive in many parts of the world including India. It is found in semi-aquatic and moist areas and a weedy species in paddy fields (Gupta 2011). It is highly likely that *E. gracilis* with similar habitat requirements might become agricultural pest especially for rice paddy. It has been estimated that an overall economic losses of the tune USD 4420 million for rice paddy due to weeds (Gharde et al. 2018). Apart from the loss to agricultural crops, this species might also invade marshes and other wetlands.

ENM provides a useful tool in early detection and in managing of invasive species and are cost effective, easy to use and widely used as early detection and warning platform that allows identification of areas, which are vulnerable for the potential invasion (Gormley et al. 2011, Guisan et al. 2013, Kariyawasam et al. 2019). The ENM also helps in prioritizing the regions for the management of invasive species. Given increase in tourist movement and amateur naturalists photographers, mobile based app and Citizen Science initiatives can be effectively used in on field and real time detection (Roy et al. 2012). The information could then be passed on to the forest department for eradication at early stages. Apart from these, electronic and print media could be used to create awareness and for management of this species. Awareness among lay public and farmers needs to be created in order to detect early and eradicate them. Given the cost involved in controlling invasive species especially in the developing country like India, early detection and control is cost effective rather than delayed response.

How quickly will the species will spread?

Many species need a lag period which could be anywhere from few years to few decades before they become invasive. For example, *Lantana camara*, which was introduced as an ornamental plant in the early 19th century became one of the most notorious invasive species only in the late 20th century. Unless detailed studies and adequate precautions are taken, *E. gracilis* could become invasive like other species. Our study indicates that the species is likely to spread in the near future and the species could occupy large landscapes by 2080. *Parthenium, Heptis* and other species became invasive in India due to initial neglect in managing the species after it first appeared in India. Hence, a priori identification, assessment and control is the key for management of newly introduced species. Future research should focus on the reproductive potential and control mechanisms. This study proactively aims to assess the potential distribution and future spread of this alien species in the Indian landscape. Early detection, and identification of probable areas of spread under present and future climate is the key for successful management of the potential invasive or weedy species.

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Authors' contribution: NAA and GR concived the idea and wrote the MS. BC collated the data and performed analysis.

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