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RESEARCH ARTICLE

Road as a major driver for potential distribution of the invasive giant African land snail in Nepal

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Abstract
Biodiversity loss is increasing globally due to many anthropogenic factors including invasive species. Among the invasive species, the giant African land snail which is World's worst invasive species is threatening the native species and become major pest for economy loss. Although the impact of snail is widespread in Nepal, we have little knowledge on their distribution and spreading factors. Using species distribution modeling, we found more than 50% of their potential area at Tarai region followed by Siwalik (29%) and 20% in mid-hill regions. The findings indicated that the species has potential for spreading to the high-mountain areas due to road and transportation. Inspite of past history of the species occurrences, the current distribution expanded across the entire country in the low lands and mountain regions. Therefore, we recommend government to prevent the potential spreading of the giant African land snail in Nepal by developing and devising policy measures to control the species in and around the roadsides. In addition, we suggest the government for proper cleaning of vehicles and transporting materials before transportation or area specific quarantine through public awareness.

Keywords Distribution modeling · Invasive species · Public awareness · Tarai region · Threats · Transportation

Introduction

Biodiversity loss is rapidly increasing worldwide (Ceballos et al. 2015), with poaching (Brooks et al. 1997), habitat fragmentation (Fahrig 2003), and the spread of invasive species (Kohli et al. 2004). Invasive species can threaten biodiversity through encroachment and habitat loss (McNeely et al. 2001; Bhattarai 2012), introduce disease risk to humans (e.g., McNeely et al. 2001; Vilà and Hulme 2017), and cause economic loss (Essl et al. 2017). The giant African land snail (GALS; *Achatina fulica*), categorized as one of the World's Worst Invasive Alien Species in 2000 (Lowe et al. 2000) poses threats to native biodiversity and humans (Budha 2015). The increased rate of distribution and risk associated with this invasive species has been generally escalating due to rapid human population growth and related activities through environmental disturbances (Pimentel et al. 2001), and human infrastructure developments including road. Therefore knowledge of current and potential distribution of these invasive species is necessary for their proper management.

Species distribution models (SDMs) are widely used to predict species' potential distributions (Pearson et al. 2007; Elith and Leathwick 2009; Kandel et al 2015; Kunwar et al. 2020; Sharma et al. 2020). Fundamentally, these models predict species' potential habitat based on the variables available at locations where the species' was verified present. There are many techniques to develop SDMs, however, machine learning and multivariate statistics through maximum entropy techniques (Maxent; Phillips et al. 2006)

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are among the best performing model approaches using presence-only data (Phillips and Dudík 2008; Elith et al. 2011). Moreover, maxent models perform well for species whose detailed spatial information is poorly known (Phillips et al. 2004), including estimation of alien species potential distributions.

The road extension and expansion is rapidly increasing as a part of development in Nepal. The vehicles and transporting materials are supposed to introduce invasive species in new areas including agricultural lands. To reduce adverse effects of GALS such as agricultural crop damage, people kill the snails and their eggs by manual collection (Peterson 1957; Olson 1973). However, the detail information of the species, their current and potential distribution is little known in Nepal. Due to the broad potential distribution of GALS and the damage they cause, understanding the distribution of this species in Nepal is important to policy development for its management and control. Our objective was to identify the potential distribution of GALS in Nepal as a baseline for developing effective management strategies.

Materials and methods

Nepal comprises 1,47,516 km^2 and is bordered by India on three sides and China to the north (26.22°–30.27° N, 80.04°–88.12° E; Fig. 1). Nepal is divided into five physiographical regions which occur from south to north: Tarai (< 300 m elevation), Siwalik (300–1000 m), Mid-hill (1000–3000 m), mid-mountain (3000–5000 m) and high mountains (> 5000 m).

We assumed GALS are spread primarily by humans in vehicles through road networks (Numazawa et al. 1988). Therefore, we established a series of 124 plots (100 × 100 m) along roads across Nepal at 5 km intervals (Fig. 1). We established plots parallel to, and within 2 m from the edge of roads, searched each for up to 60 min or until a GALS was detected. We also collected presence locations from opportunistic observations and through locations visited following personal communications with local people. We confirmed GALS occurrence if we found at least 1 live individual or its shell in the plot. We collected data from May 2019 to October 2019. Finally, we also used GALS occurrence points from Rawat (2018).

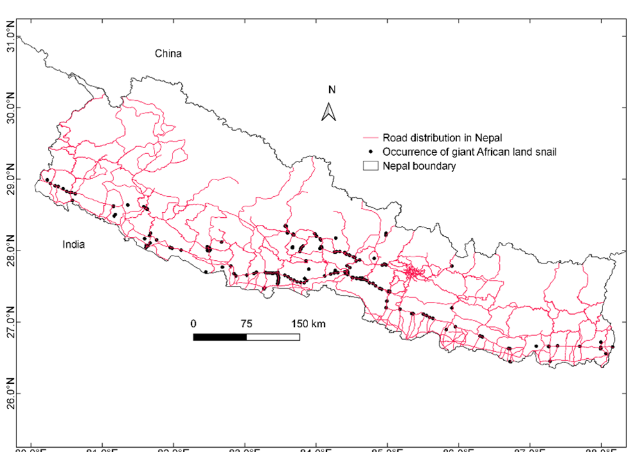

Fig. 1 Occurrence locations (black circles) of giant African land snail, Nepal. Brown lines represent roads

We used maximum entropy techniques (Maxent; Phillips et al. 2006) to predict the potential distribution of GALS. Maxent provides high performance for modeling species distributions using presence-only data (Elith et al. 2011), including predicting habitat suitability of invasive species with high accuracy, even with limited observations (West et al. 2016). To model GALS distribution, we initially used 19 bioclimatic variables at 30 arc resolution (ca. 1 km^2) from Worldclim (https://worldclim.org/; Hijmans et al. 2005), and road (https://data.humdata.org/dataset/nepal-road-network). We further verified road data from Nepal Road Network developed by Government of Nepal, Department of Road (GoN 2015a, b). We developed a raster layer of road with Euclidian distance and upscaled the raster layer to 30 arc (*ca.* 1 km^2) resolution based on the mean values of the raster cells. We converted the road into Euclidian distance in QGIS. We reduced the raster file using a mask of Nepal's boundary converted the file to the Nepal Projection system (i.e., Modified Universal Traverse Mercator). We then ran Maxent using default settings to select suitable variables. Using Jackknife and correlation analyses, we included only those variables which were not highly correlated ($|r| < 0.70$; Fig. 2; Supplementary Figure S1, S2 to avoid model overfitting (Graham 2003). We divided the occurrence data into subsets of 75% and 25% records as training and test data sets, respectively. We then ran Maxent using these selected variables with linear and quadratic forms to constrain the variance of the predictors (Elith et al. 2011). We converted the Maxent output using the maximum Training Sensitivity plus Specificity Logistic Threshold to identify suitable and unsuitable habitat (Liu et al. 2016) and calculated the potential area. We evaluated model performance using area under the curve receiver operating characteristics (AUC) and true skill statistics (TSS), sensitivity and specificity (Allouche et al. 2006; Lobo et al. 2008).

Results

We acquired 266 presence records for GALS; 80 from plots searched, 178 from opportunistic observations, and 8 from Rawat (2018) (Fig. 1). The model had good performance as indicted by AUC (0.933), TSS (0.775), sensitivity (0.896), and specificity (0.880) values. Distance to nearest road

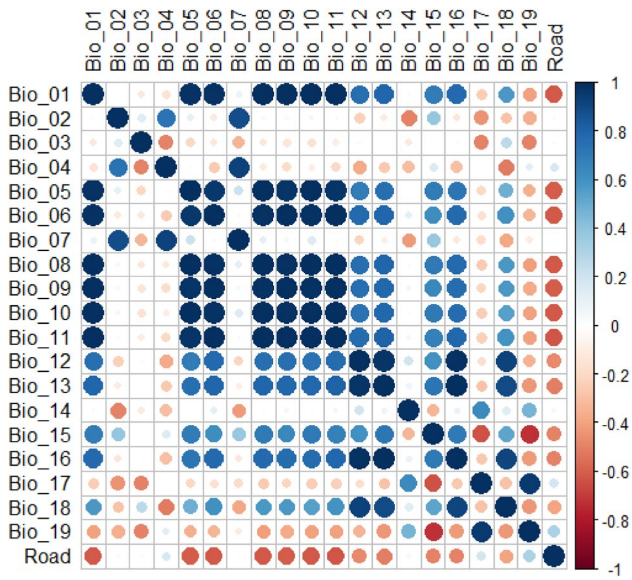

Fig. 2 Spearman pairwise correlation coefficients between predictive variables (see Table S1 for descriptions) considered in the giant African land snail model. Variables selected for the final model were not highly correlated (|r| < 0.70)

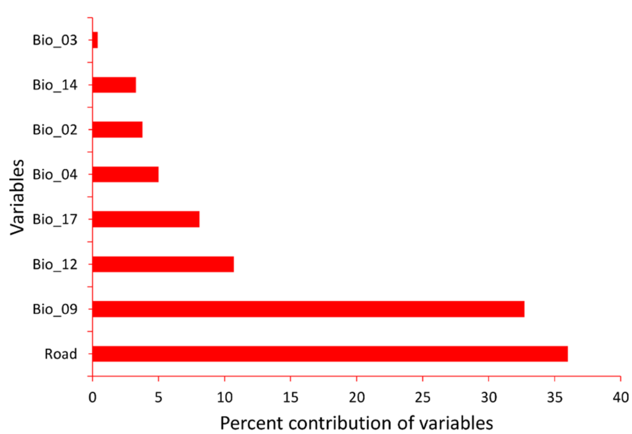

Fig. 3 Percent contribution of variables in final giant African land snail's potential distribution model, Nepal: Bio_02 (mean diurnal range), Bio_03 (Isothermality), Bio_04 (temperature seasonality), Bio_09 (mean temperature of the driest quarter), Bio_12 (annual precipitation), Bio_17 (precipitation of the driest quarter) and Road (Euclidian distance)

(35%), mean temperature of the driest quarter (Bio_09; 33%), and annual precipitation (Bio_12: 10%) had the greatest percentage contribution for predicting potential GALS distribution, followed by precipitation of the driest quarter (Bio_17), temperature seasonality (Bio_04), mean diurnal temperature range (Bio_02), precipitation of the driest month (Bio_14), and isothermality (Bio_03) (Fig. 3). Probability of GALS was found higher in near to road (Fig. 4) and the areas within about 900 m of roads were most likely to support occurrence of GALS (Table 1). The mean temperature of the driest quarter (Bio_09) of the potential predictive areas ranged from − 2.4 to 23.3 °C (mean = 16.6 °C) whereas the range of annual precipitation was 363–4377 mm (average: 1877 mm) (Fig. 4).

The maximum training sensitivity plus specificity threshold to categorize areas as potentially suitable was 0.277. At this threshold, the model predicted 17,244 km^2 as potential suitable habitat for GALS (Fig. 5). Most of the potential distribution of GALS was in the Tarai (51%) and Siwalik (29%) physiographic regions, followed by the Mid-hills (20%), mid-mountains (1%), and negligible in high mountains (Fig. 5).

Discussion

The disproportionately greater distribution of GALS throughout the lowlands of Nepal (Tarai and Siwalik physiographic regions) indicates the potential risk of this species on vegetable and crop production since the low land lies to the South of mid-hills, serves as the rice bowl of Nepal today. Currently, the presence of GALS in these areas is problematic because of foraging on crops and the species high reproductive capacity (Sadarline 2019). Giant African land snails directly impact about 65% of Nepalese people involved in agriculture, with agriculture contributing 31% of Nepal's Gross Domestic Product (GoN 2015a, b). Surprisingly, GALS occurrence was also projected in the mountain regions; we detected the species as high as 2095 m elevation which suggests upward elevational spread of this species in Nepal. The current spatial distribution of the species was largely within 1 km of roads, though this was undoubtedly influenced strongly by our sampling protocol.

Distribution of GALS within Nepal has apparently increased markedly during recent years. Budha and Naggs (2008) mentioned its western distributional limit to central Nepal; however, GALS now occur across the entire country. Despite the negative effects of GALS to agriculture and the loss of native biodiversity (Kohli et al. 2004), people transport GALS to their homes for worship, ornamental, and medicinal purposes (Agbogidi and Okonta 2011; Alves et al. 2012). In some cases, we found people transporting the species for use of the shell's whorl because in Nepalese culture the larger shell of Mollusca are used as symbols of worship (Sharma, H.P., personal observation). In addition, the species is transported from the Tarai to mountainous regions through construction material such as sewer pipes (Baral, K. District Forest Office, Tanahun, personal communication).

An optimal thermal condition for GALS is between 15 and 24 °C (Thompson and Cheney 1996). Therefore, the current distribution in lowland and mountain regions of

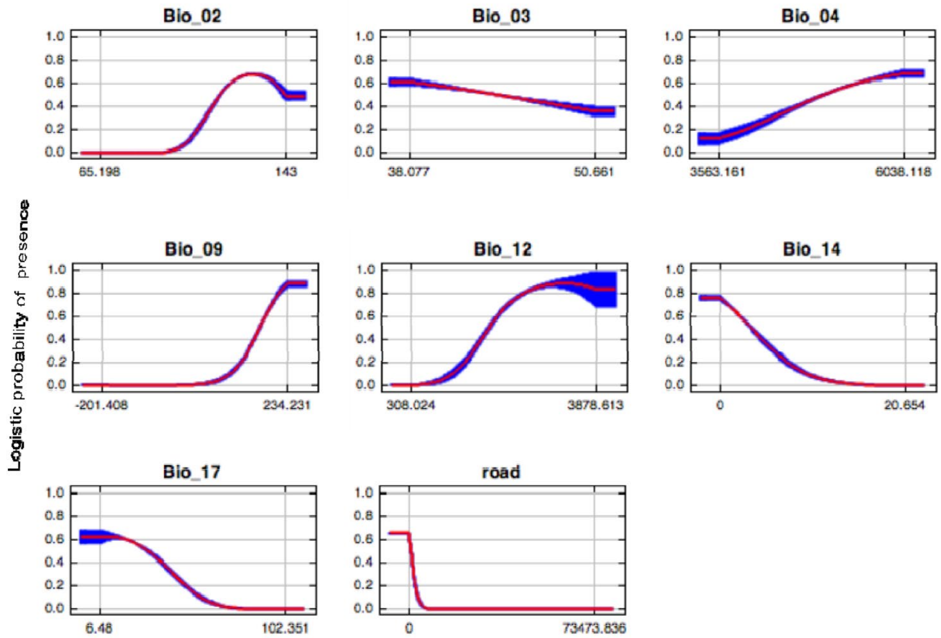

Fig. 4 Response curves of variables in giant African land snail's potential distribution model, Nepal: Bio_02 = mean monthly diel temperature range, (°C); Bio_03 = isothermality (°C); Bio_04 = temperature seasonality (°C); Bio_09 = mean temperature of the driest quarter (°C); Bio_12 = annual precipitation (mm); Bio_14 = precipitation of driest month (mm); Bio_17 = precipitation of the driest quarter (mm); road = distance to nearest road (m)

Table 1 Values of predictive variables in potential distribution area of giant African land snail

Variable	Minimum	Maximum	Mean	SD
Bio_02 (°C)	10.2	14.1	11.73	5.5
Bio-03 (°C)	4.0	4.9	4.4	1.8
Bio_04 (°C)	404.9	591.2	498.6	40.3
Bio_09 (°C)	− 2.4	23.3	16.6	2.1
Bio_12 (mm)	363	4377	1877	430
Bio_14 (mm)	0	12	3.5	2.0
Bio_17 (°C)	5.0	64	28.66	10
Road distance (km)	0	4.633	0.903	0.85

Nepal where temperatures are > 15 °C was not surprising. Survival of GALS is influenced by temperature seasonality and precipitation, with higher abundance found during the monsoon (June–August) when temperature range 15–23 °C (Rangarajan et al. 2013). Dettman et al. (2004) also identified greater growth rates of gastropods during the monsoon.

Giant African land snails feed on more than 500 plant species (Capinera 2011) which includes cultivated plants. Crop damage in Nepal varies from slight to complete, with greatest damage to crops belonging to the families Cruciferaeae, Cucurbitaceae, and Leguminoseae (Sharma, H.P., personal observation). The species also is a serious pest of

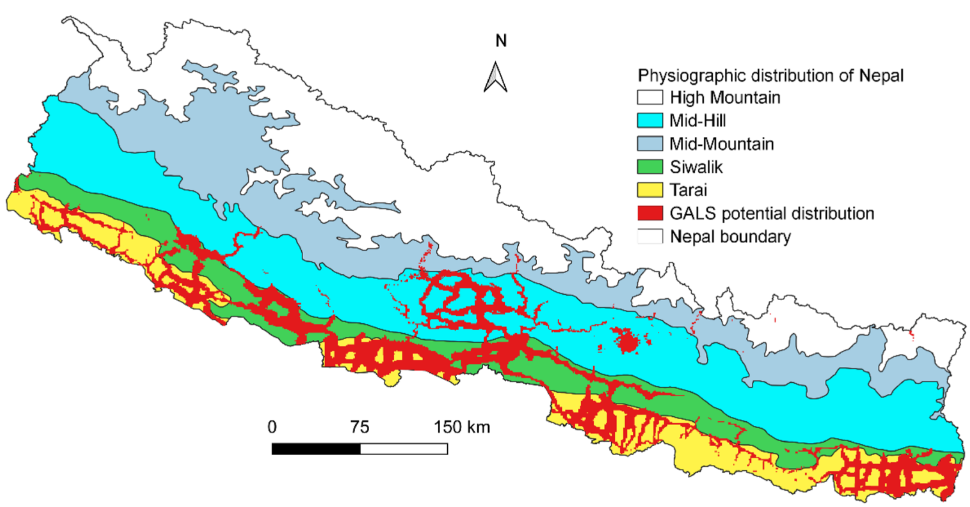

Fig. 5 Potential distribution (red areas) of giant African land snail in Nepal

vegetables, foraging on young plants in nursery beds (Budha and Naggs 2008) and is a major problem in home gardens (Albuquerque et al. 2008; Budha and Naggs 2008). Giant African land snails also can displace native terrestrial mollusks (Thiengo et al. 2007).

Currently, people in Nepal kill GALS and their eggs by manual collection, then place them in plastic bags and pour salt or chemicals over the individuals. However, long-term broad scale use of salt in agricultural fields can increase soil salinity and adversely influence crop production. Use of metaldehyde pellets was effective to manage snail populations (Sharma and Agarwal 1989) but can reduce survival of non-target snails, including endemics fauna (Prasad et al. 2004). Therefore, alternative control methods are needed to reduce the losses from GALS.

Conclusions

The impacts of GALS on biodiversity and economic losses in Nepal are not known, though the potential for adverse effects are clear (ISSG 2003; Lowe et al. 2000). Because of the widespread and rapidly increasing distribution of GALS, and corresponding damage to agricultural crops and native biodiversity, we recommend the Government of Nepal develop strategies to control the distribution of this species within its border. As the distribution of GALS is strongly associated with transportation by vehicles, we recommend the Government consider implementing a task force to inspect for GALS in vehicles and transport materials with higher likelihood of occurrence, such as construction vehicles. Efforts could be emphasized in the Tarai and Siwalik physiographic regions where GALS occurrence is greatest. Consideration of a national educational program, perhaps part of an overall invasive species awareness program, to inform citizens of the adverse environmental and economic effects of GALS is warranted. Finally, considering and promoting alternatives to the use of GALS in Nepali cultural could further reduce the spread of this species.

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