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Mapping invasion potential using ensemble modelling. A case study on *Yushania maling* in the Darjeeling Himalayas

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ABSTRACT

Biological invasion is considered the subsequent most important threat to biodiversity after habitat destruction and is documented as a main cause of global biodiversity loss and species extinction. Species distribution models can be used to identify areas that are at risk for invasions by harmful invasive alien species (IAS) if IAS have not yet spread to all suitable habitats. We tested the potential of combining two or more independent but complementary modelling methods to enhance the accuracy of spatial predictions. We used the modelling tools Maxent, GARP and BIOCLIM with presence-only data of the IAS *Yushania maling* (Maling bamboo), from Darjeeling, Himalaya to develop distribution maps. Modelling tools were chosen based on their performance with presence-only data (Area under curve (AUC) > 0.7) as well as their differences in underlying modelling concept and statistics. The models combine occurrence records with topographic, climatic, and vegetative predictors derived from satellite data. By combining the 3 selected models in an ensemble approach we were able to minimize the spatial uncertainty related to suitable habitat prediction for *Yushania maling.* While both GARP and BIOCLIM consistently performed at an AUC > 0.7, both our ensemble model and Maxent performed better with an AUC of 0.95 and 0.94 respectively. Moderately and highly suitable habitats for *Yushania maling* predicted by models correlated well with survey records except for GARP, where we found the model to over-predict suitability outside of the species' known ecological niche. Our findings identify the best modelling approach enhancing overall explanatory power of habitat suitability models. Our findings show that an ensemble approach should be used to ensure appropriate mitigation measures are applied in the appropriate places, enhancing overall effectiveness both ecologically as well as economically. It was shown that *Yushania maling* is indeed a threat to the ecosystems in the region, and while the species' potential habitat may decrease in some areas with climate change, other areas will become more suitable for it.

1. Introduction

The Darjeeling district in the Himalaya region, India, is a hotspot for biodiversity, endemism and micro-diversity. Over past decades, rapid population growth has led to increasing anthropogenic disturbances in the region and a consistent increase in pressure on the environment. The inflating level of anthropogenic activity, a growing ecological susceptibility due to climate change, disturbances and other factors make the area prone to invasions by non-native species. Invasive alien species (IAS) are species that are capable of getting established outside their natural ranges. They commonly show a high potential for spread and can become established outside their historical range, causing – often irreversible - damage to the environment. Biological invasions have led to the extinction of thousands of endemic species in the past few hundred years (Mooney and Drake, 1987) and have homogenized the world's flora and fauna (Hobbs, 2000). In the Darjeeling region, such invasions are causing considerable ecological damage to the native flora and fauna (Sekar, 2012). *Yushania maling* (Gamble) is a native invasive species to the region. The species was previously known as *Arundinaria maling* (Majumdar et al., 1989), in the *Yushania* genus of bamboo in the grass family. Starting in the late 1980ies first occurrences were recorded in India's Darjeeling district (Chi-son and Renvoize, 1989). Since then, the species has been spreading at an alarming rate, damaging the native fauna and flora (Roy et al., 2016) by

Abbreviations: AUC, area under curve; DEM, digital elevation model; EM, ensemble model; IAS, invasive alien species; LULC, land use land cover map; mamsl, meters above mean sea level; NP, national park; ROC, receiver operating characteristic; SDM, species distribution model; WLS, wildlife sanctuary

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rapidly outcompeting native species (Stapleton, 1997).

The management and mitigation of IAS has been at the center of attention of scientific research for many decades (Elton, 1958). While numerous studies demonstrate the dramatic effect of invaders on recipient ecosystems (Mack et al., 2000), other studies are working towards possible ways to tackle the challenges arising from biological invasions. Guisan and Zimmermann (2000); Scott, (2002) as well as Guisan and Thuiller (2005) for example demonstrate the importance of species distribution modelling (SDM) in general, and describe a variety of methods available for the prediction of a species' potential habitat. Jiménez-Valverde et al., (2011) advocate the role that SDM can play in risk assessment and conservation. Timely information about areas under risk of being invaded can help in devising effective control and eradication strategies, aiding decision making by resources managers, government agencies, and non-government organizations.

One way to identify potential areas of spread of invasive species is through modelling their current distribution (Padalia et al., 2014), followed by species-environment matching for areas outside a species current range. The accuracy and performance of individual SDM varies widely among methods and species (Elith et al., 2006; Marmion et al., 2009). Methods integrating multiple individual models provide robust estimates of potential species' distributions (Araujo and New, 2007; Marmion et al., 2009). Ensemble maps that highlight areas of agreement among model predictions offer a way to reduce the uncertainty of basing management activities on solely one SDM model. The importance of study manifolds taking into account that there are limited related studies in the past.

An increasing availability of spatial data, as well as high resolution bio-climatic data have continuously enhanced the prerequisites needed for successful SDM and assessment of factors affecting the magnitude and extent of a potential invasion. Using such data, Ensemble Models (EM) have the potential to provide more robust estimates of suitable habitat for a given invasive species at a given time (Meller et al., 2014; Poulos et al., 2012), leading to robust SDM. In EM the predictions of a group of base models are combined to generate more accurate composite predictions. Particularly when analysing the risk of IAS that have not yet spread to all suitable habitats the determination of species-environment relationships can be challenging (Stohlgren et al., 2010). In such cases, EM have the potential to highlight areas of agreement among models, using a range of modelling techniques (Araujo and New, 2007; Marmion et al., 2009; Stohlgren et al., 2010).

In recent years, EM methods have been improved in a variety of ways to produce more accurate estimates of species distribution and to facilitate conservation measures. For e.g., Comte (2013) assessed the influence of species non-detection in modelling species distributions with an ensemble consensus approach and compared it with an occupancy model that accounted for species imperfect detection and found consensus models to outperform the occupancy models for the highly detectable species. Forester et al., (2013) integrated two independent-complementary methods, EM and statistical phylogeography and produced robust assessments of climate change impacts on species distributions. Whereas, Meller et al., (2014) evaluated and compared the pre-selection and post-selection consensus approaches in conservation prioritization. Breiner et al., (2015), in addition to introducing fresh approach of using ensembles of small models (ESM) to model the distribution of rare species, tested the approach more comprehensively on a large number of species including a transferability assessment. Recently, Naimi and Araújo (2016) created a R based platform for species distribution modelling, enabling ensembles of models to be fitted and evaluated. The R package can generate ensembles of SDMs and offers variety of options for the evaluation of the produced projections of species potential distributions in space and time. A very recent R package "ecospat" developed by Cola et al., (2017) provide adequate functions to run the very recently proposed ensemble of small models (ESM) approach (Breiner et al., 2016). Further, using the R based package "BIOMOD2" devloped by Thuiller et al., (2016); Gillard et al., (2017) performed ensemble forecasting by using nine different algorithms including: three regression based methods, two classification based and four machine learning methods to forecast current and future potential distribution of three invasive plant taxa.

While it is generally understood that SDM derived using EM can have a stronger explanatory power than SDM from individual models, little is known about both the ideal combination of base models in an EM, and whether or not the benefits of EM shown for well researched cases can also be obtained when working with limited data from specific case study regions, where decision makers are facing pressure to act. In a first step we therefore assess our first hypothesis:

H0,1. Model performance of Maxent, GARP and BIOCLIM is similar to that of EM when using field data for *Yushania maling*.

Successfully deriving an ideal modelling approach using limited real-world data will additionally allow us to investigate a second hypothesis, directly aimed to assist decision makers.

H0,2. The spread of *Yushania maling* is limited. No currently unaffected areas in the region are at risk of being invaded.

By answering this hypothesis areas under risk can be identified and required policies can be developed to ensure timely and appropriate counter measurements are implemented. When it comes to ensuring a longer-term applicability of answer to these two hypotheses it becomes evident that climate change has to be addressed as well. Climate change might impact the distribution and potential habitat of invasive *Yushania maling* and eventually affect the effectiveness of control measures. Therefore to identify the impacts of climate change on potential distribution of *Yushania maling* and to aid the long term IAS management plan, we investigate our third hypothesis.

H0,3. There is no difference in the potential habitat of *Yushania maling* under a changing climate.

2. Methods and material

To answer our hypotheses, occurrence data was collected that, together with additional data on bio climate and other ecological parameters were used to develop an EM. In the following, we will be describing the study area, our approach for collecting data in the field, as well as the approach used for modelling.

2.1. Study area

The study area is located in the Darjeeling Himalayas (Fig. 1), India. The area is located at 87°59′ E - 88°53′ E to 27°14′ N - 26°27′ N and includes the Himalayan parts of Sikkim, Nepal, Bhutan and Bangladesh encompassing an area of 8812 km^2

The region is home to a diverse alpine flora belonging to 60 families and 297 genera covering 60% of all alpine plant families and 10% of all the alpine genera known worldwide (Körner, 1999). The total number of vascular plant species recorded across the region (1400 ± 75 species) is more than double of that recorded for the European Alps, New Zealand Alps and the Rocky Mountains region (600–650 species) (Mark and Adams, 1973; Hadley, 1987; Ozenda, 1995). Remarkably, the Darjeeling Himalayas region is one of smallest regions in terms of geographic area, yet has the highest number of species per km^2.The area covers 3 national parks and 7 wildlife sanctuaries (Singalilia NP, Neora Valley NP, Gorumara NP, Jorepokhri Salamander WLS, Senchal WLS, Mahananda WLS, Chapramari WLS, Pangolakha WLS, Barsay WLS, and Kitam WLS). The area is additionally covering a variety of climatic zones with distinct attributes, leading to a comparably high overall biodiversity. The region is also a source of vast variety of medicinal plants, which are extensively used by local communities. About 400 plant species, mostly herbaceous endemics of high medicinal value, are harvested in the high elevation grasslands of Sikkim