Invasive Species Risk Analysis Using Ensemble Modelling Technique

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CERTIFICATE

This is to certify that **Mr. Vivek Srivastava** has carried out his project entitled **"Invasive Species Risk Analysis Using Ensemble Modelling Technique",** in partial fulfillment for the award of degree of **Master of Technology in Remote Sensing and GIS**. The project has been carried out in **Forestry and Ecology Department** and is original work of the candidate under the guidance of **Dr. Hitendra Padalia**, Scientist/Engineer-SE, at Indian Institute of Remote Sensing, Dehradun, India.

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ABSTRACT

Biological invasion is considered as the second most important threat to biodiversity after habitat destruction and is recognized as a primary cause of global biodiversity loss and species extinction. Species distribution models may be particularly useful in risk analysis of recently arrived, harmful invasive species because species may not yet have spread to all suitable habitats. Ensemble species distribution models combine the strengths of several species distribution models, while minimizing the weakness of any one model. We used three well-known species distribution modelling methods for presence-only data to produce ensemble prediction maps for three invasive species i.e. *Yushania mailing*, *Chromolena odorata,* and *Hyptis suaveolens* for present scenario in Darjeeling Himalaya. Maxent, GARP and BIOCLIM were chosen for inclusion based on their good performance with presence-only data and because they differ both conceptually and statistically. The models are based on occurrence records combined with topographic, climatic, and vegetation predictors derived from satellite data. We also modelled future distribution of selected invasive species under HADCM3 A2a and B2a, 2050 climate change scenarios using Maxent modelling approach. In this study attempt was made to prioritize/delineate risk zones at realized niche levels of the concerned species i.e. at the local level of the species occurrence using a novel multi-criteria risk zonation approach. To delineate invasive species risk zones ensemble habitat suitability outputs for individual invasive species and risk determining factors like vegetation type, conservation status, species diversity and disturbance source (land use, road length) were considered. For the three invasive plant species tested, Maxent model was the only model that ranked in the top three models for both field validation and test data. Ensemble models may be more robust than individual species-environment matching models for risk analysis

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1 INTRODUCTION

1.1 Biological Invasion

Biological invasion is considered as the second most important threat to biodiversity after habitat destruction. Alien species which locally becomes dominant and invade natural communities, are referred to as invasive species. Invasive species are so much important in the present scenario that, article 8(h) of the Biodiversity Convention asks for measures ‘‘to prevent the introduction, control or even eradication of those alien species which threaten ecosystems, habitats or species’’. Biological invasion has been homogenizing the world’s flora and fauna (Hobbs 2000).

The term invaders and invasion in an ecological context was first described by Elton, “the father of invasion ecology” in his classical book on invasion (Elton 1958). Since then, a number of definitions of invaders and invasion have been proposed. According to di Castri (1990), “A biological invader is a species of plant, animal or micro-organism which, most usually transported inadvertently or intentionally by man, colonizes and spreads into new territories some distance from its home territory. IUCN (1999), also defines alien invasive species, as a species that becomes established in natural or semi-natural ecosystem or habitat, is an agent of change and threatens biological diversity. Further, Kolar and Lodge (2001), defined invasive species as “a non-indigenous species that spreads from the point of introduction and becomes abundant”.

These invaders could be plant, animal or microbial species. Invasive species, owing to their aggressive nature can expand their zone of occupancy in quick succession, spread over large tracts, and endanger the natural elements of flora and bring about abrupt changes in floristic composition. With seasonal variations invasive species pass through vigorous reproductive phases without any obstruction and hinder the efforts to eradicate them.

Invasive plants have appeared at different times and have always sustained and multiplied at the cost of indigenous species. They have occupied vast areas and have even driven many indigenous species into red data categories. Invasive species can harm both the natural resources in an ecosystem as well as threaten human use of these resources. Invasive species are capable of causing extinctions of native plants and animals, reducing biodiversity, competing with native organisms for limited resources, and altering habitats. This can result in huge environmental and economic impacts. Irrespective of this invasive species are also useful as they are being used for various purpose ranging from medicinal uses, attachment to religious sentiments to uses in furniture, compositing etc. Invasive species modify all the major ecosystem processes in the way, which suits them best. The first and foremost impact seen on an invaded ecosystem is alteration in litter dynamics. Gradually other ecosystem processes depending on litter dynamics *viz.* soil biota, nutrient dynamics and biogeochemical cycles are also modified. Later, geomorphology and hydrology of the area are also changed as invasion proceeds. During the course of establishment these invasive species also interfere with native species recruitment either by allelopathic suppression or by competing with seedlings for resources. The invasive species are also known to alter fire regimes.

Plant invasion occur in three stages: *Introduction, Colonization and Naturalization*. The propagule of invasive species takes the advantages of invasion window created by disturbance within the ecosystem from natural or man-made factors. It outcompetes the environmental, reproductive and dispersal barriers in the invaded area and rapidly spread its population. Environmental factors like resources availability favoring establishment of alien propagule are believed to be the most important at introduction phase because introduced propagule has to compete with the established native flora that is already well adapted to the site. Factors which play a key role in the successful establishment and survival of these species are unrestrained vegetative spread, escape from biotic constraints, prolific seed production, highly successful seed dispersal, germination, and colonization, adaptive morphological and ecological characters, superior propagule characteristics favoring greater mobility, and ability to supplant native flora either competing for resources or exerting allelopathic effects.

1.2 Invasive Species Ecology

In this study three invasive species were selected from the study area i.e. *Yushania mailing*, *Chromolena odorata,* and *Hyptis suaveolens*. Their ecology is described below.

Yushania mailing formerly called *Arundinaria mailing* (Majumdar and Karthik 1989) found in India, Darjeeling district, (Chao and Renvoize 1989). It is also a common component of the temperate forest understory in eastern Nepal and southern Bhutan, (Stapleton 1994). *Yushania mailing* is a plant of high altitude (FAO 1996). It is locally known by different names such as maling, malingo, khosre malingo (Nepali).It attains up to 3 meters / 10-15 feet in height . Its distribution in Nepal eastern part is at 2100-3200 m altitude. In Bhutan Southern part (chukkha district) it is found at an altitude of 2100m and in India it is found in Sikkim, West Bengal (Darjeeling) at1600-3600 m,(Mallick and safui 1987) , Assam Balipara frontier track at 3000 m altitude (Bor 1940), Arunanchal Pradesh at 1800-2750m altitude (Lessard and Chouinard 1980) .

Occurrence of *Yushania mailing* is reported in protected areas like Khangchendzonga Biosphere Reserve, Mahananda-Neora Valley, Senchal-Mahananda and

Singhalila-Senchal (HKH Conservation Portal, ICIMOD). It is generally widespread and dominant, common component of temperate forest understory grows on mountain slopes and ridges particularly forming dense thickets often associated with Tsuga and Rhododendrons and reported with scattered trees of Acer, Takus, Magnolia, Betula, Quercus etc., and occasionally with other bamboos . *Yushania mailing* attains up to 3 meters / 10-15 feet in height. It prefers well drained soil ranging from Sandy Loam to Clay Loam. It requires abundant moisture and plenty of organic matter in the soil. It tolerates temperatures down to about -5°c and is probably best grown under protection. This bamboo has rhizomes that are clumping rhizome type, but because it is so vigorous and has long rhizome "necks", which makes it to be a spreading bamboo and can be highly invasive. New shoots are produced from late May. Plants only flower at intervals of many years. They are large, vigorous species that often form dense, impenetrable thickets, and can suppress tree regeneration if clear-felling removes the canopy completely. They are resilient bamboos with rhizomes that penetrate to considerable depth. They occupy ecologically similar habitats and survive in what are, for bamboos, relatively dry sites. They have few uses and can be categorized as pernicious weeds.

Chromolaena odorata (family Asteraceae, sub-family Lactucoideae tribe Eupatoriae; commonly known as Syam weed) is a Central American shrub that has become highly aggressive invasive throughout many tropical countries (McFadyen and Skarratt 1996). *C. odorata* was originally classified as *Eupatorium odoratum* L. but subsequent revision by King and Robinson (1970) resulted in the species being assigned to the genus *Chromolaena*. *Chromolaena* is a multi-stemmed perennial shrub, forming monospecific stands up to 2.5 m tall in the open and dense scrambling bushes up to 10 m high among trees. The fibrous root system is extensive and shallow (20 – 30 cm). Leaves are sparsely hairy, occur in pairs and are pointed ovate to triangular. They vary in colour from light to medium green and have three conspicuous veins. They have a distinctive smell when crushed. Flowers are clusters of mauve to off-white (Bingelli et.al. 1998; Caldwel 2000; McFadyen 1991). *C. odorata* has a ruderal strategy and occurs in a wide range of environments including road verges, neglected agricultural fields and as an understorey species in forest. As a heliophyte (Gautier 1992), it requires sufficient light to grow and produce seeds (Witkowski and Wilson 2001).

Chromolaena odorata reproduces sexually. Plants are apomictic. Flowering is short and fairly synchronous, beginning in June/July, and appears to be initiated mainly by the onset of the dry season. Terminal cymes bear about 70 insect-pollinated flowers. *C. odorata* produces a large number of light weight pappus bearing seeds that are released in July/August (Witkowski and Wilson 2001). The seeds are dispersed by wind up to about 80 m. However, as the seeds have small spines and can cling to fur, feathers and clothes, long distance dispersal also occurs. Seeds can also travel great distances with contaminated crop plants or vehicles (Blackmore 1996 and Witkowski and Wilson 2001). *Chromolaena* *odorata* germination is positively influenced by light intensity (Witkowski and Wilson 2001). Reports of seed viability vary from 1 - 2 years.

The worldwide range of expansion and the large economic and ecological impact of this species has been widely addressed (Epp 1987; De Rouw 1991; Gautier, 1992; Akpagana et.al. 1993; McFadyen and Skarratt 1996; McWilliam 2000; Leslie and Spotila 2001). It has been therefore listed among the one hundred of the world's worst invasive species (ISSG 2004).

Hyptis suaveolens (L.) Poit. (bushmint, pignut) is a soft suffrutescent and broadleaved herb or shrub belonging to the family Lamiaceae. *H. suaveolens* is among the world's most noxious exotic invasive species, which are invading natural ecosystems at an alarming rate across various parts of world (Padalia et.al. 2013). It has been regarded as a pantropical weed because of its widespread distribution from tropical to subtropical regions of the world (Wulef and Medina 1971; Monasterio and Sarmiento 1976; Sarmiento 1984; Afolayan 1993). In India, *H. suaveolens* is well established in northeast India, Vindhyan highland, Deccan Peninsula, and even in the islands of Andaman and Nicobar (Yoganarasimhan 2000).

Hyptis is of common occurrence along the rail tracks, roadsides (Verma and Mishra 1992), foothills of open forests, forest clearings (Mudgal et.al. 1997) and can heavily infest wastelands particularly arid and rocky substrates. *H. suaveolens* has been regarded as a ruderal weed (Walter 1963) as it is capable of heavy infestations by physically occupying the land and displacing native flora. It is known to produce allelochemicals that impede seed germination of associated species. Besides the harmful effect of *H. suaveolens* on the local biodiversity, the plant is a potential source of medicinally useful constituents. It is reported as having anti-cancerous (Mudgal et.al. 1997) and tumorigenic (Peerzada 1997) properties. But at present, the damage to the biodiversity of adjoining areas is much greater than its utilization as a medicinal plant (Raizada 2006).

Hyptis is a rigid annual herb of aggressive nature (Mudgal et.al. 1997). It starts its vegetative phase either from perrenating rootstock or viable seeds either from persistent seed bank or from fresh stock with the onset of monsoon rains. It can attain height of approximately 2.5 meters within a growing season. Its stem is quadrate and bears hair. Leaves are either ovate or obovate. Leaves are generally 3-5 cm long and 2-4 cm wide with serrulate margins and a long petiole. Lower surface of the leaves bears hairs; petioles up to 3 cm long. Flowering starts in it at an early age of two to three months. It produces copious blue flowers in small cymes along branch that ends with reduced leaves. Calyx is hairy in nature and is nearly 5 mm long in flower while it enlarges to 10 mm long in fruit and become ribbed. Corolla is blue, strongly zygomorphic and bilabiate, declinate, and about 8 mm long, with a limb 5 mm in diameter. The flower has 4 stamens. *Hyptis* flowers are pollinated by a large number of pollinators leading to enormous seed production.

Hyptis covers a large area after the rains and not allows the adjoining native species to flourish. So it has potential for a successful invader thus efforts should be done to check it's spread so that it may not become a successful invader in near future like other invaders in the Indian forests.

1.3 Species Distribution Models

Invasive species have intrigued ecologists for long (Elton 1958). Numerous studies demonstrated the dramatic effect of invaders on recipient ecosystems (Mack et.al. 2000). Timely information about the areas of current and future invasion from different sources can help in devising effective control and eradication strategies. One of the ways to identify potential areas of spread of invasive species is through modelling their distribution. Spatial modelling and species-environment matching models are becoming commonplace for natural resources managers, agencies, and nongovernment organizations who need accurate maps of species distributions and abundance for risk analysis (Stolhgren et.al. 2010). Species prediction modelling can help in generating spatial distribution maps of invasive species, area of spread and factors affecting the magnitude and extent of invasion. Current availability of high resolution bio-climatic data on various aspects of environments gives scope for precise distribution modelling.

Predictive species distribution models have an important role in ecology and biogeography and are increasingly used in a range of applications including regional biodiversity assessments, conservation biology, wildlife management and conservation planning. Prediction of potential habitat for invasive species is critical for their monitoring and restoration of declining native species populations and conservation of native species and habitat.

Ensemble models provide a simple technique to provide robust estimates of suitable habitat for a given invasive species at a given time. The main aim of ensemble modelling is to decrease the predictive uncertainty of single-models by combining their predictions, Ensemble models and maps are an essential tool in risk analysis of invasive species. Ensemble species distribution models combine the strengths of several species environmental matching models, while minimizing the weakness of any one model. Ensemble models may be particularly useful in risk analysis of recently arrived, harmful invasive species because species may not yet have spread to all suitable habitats, leaving species-environment relationships difficult to determine.

1.4 Why Niche Modelling for Invasive Species?

India is considered to be one of the twelve centres of biodiversity in the world. India accounts for 8 % of the global biodiversity existing in only 2.4% land area of the world. According to Nayar (1989), 4900 endemic flowering plant species are there in the country. India's rich vegetation wealth and diversity is undoubtedly due to the immense variety of the climatic and altitudinal variations coupled with varied ecological habitats. 173 species of invasive aliens in country were identified (Reddy et.al. 2008), Some of the widely spreading invasive species among them are *Ageratum conyzoides, Eichhornia crassipes, Eupatorium adenophorum, Chromoleana odorata, Ipomoea carnea, Lantana camara, Mikania micrantha, Parthenium hysterophorus, Prosopis juliflora, Hyptis suaveolens* etc. They have a high probability of expanding and causing great ecological damage. Darjeeling Himalaya is rich centre of endemicity and micro-diversity. Current increasing population, disturbance and pressure upon them are facilitating an invasion window which is causing considerable ecological damage to its native biodiversity. The three invasive species selected in this study were of diverse habitat. *Yushania mailing* is a species of temperate region, while *Chromoleana odorata* and *Hyptis suaveolens* are species of tropics and sub tropics with distinct habitats i.e., *Chromoleana odorata* is found around road edges, tea gardens, forest edges etc, while *Hyptis* is found along the open dry riverine areas. These invasive species are speeding the disappearance of native species. Thus, importance of this study manifolds accounting for their monitoring and restoration of declining native species populations and conservation of native species and habitat.

1.5 Research Objectives

The following research objectives were considered.

(1) To model spatial distribution of selected plant invasive species using ensemble distribution modelling technique.

(2) To define invasive risk zonation based on outputs of ensemble modelling.

(3) To predict future spread of invasive species under the IPCC climate change scenario.

1.6 Research Questions

The present study aims to answer the following research questions.

(1) What are the bioclimatic variables associated with selected invasive species distribution?

(2) What is the optimum sample size required for modelling of invasive species distribution?

(3) Where are the areas which are likely to be affected by invasion in near future?

2 Review of Literature

Studies carried out by Mooney and Drake (1987), Drake et.al. (1989), indicate that invasions caused thousands of extinctions of endemic species in the past few hundred years. Czech and Krausman (1997), recognized invasion as a primary cause of biodiversity loss. Mack et.al. (2000), has demonstrated the severe impact of invasive species on native ecosystem. Reddy et.al. (2008), listed 173 invasive species and alarmed about their rapid spread within the country.

In this study three invasive species were selected i.e. *Yushania mailing*, *Chromolena odorata,* and *Hyptis suaveolens*. Stapleton (1994); Varmah et.al. (1980); R.B.Majumdar and Karthik (1989), studied on an indigenous species of Eastern Himalayas i.e. *Yushania mailing* which is locally becoming dominant and possessing threat to local biodiversity. McFadyen and Skarratt (1996); King and Robinson (1970); Erasmus (1985); Witkowski and Wilson (2001), studied the ecology and habit of *Chromolena odorata*. Epp (1987); De Rouw (1991); Gautier (1992); Akpagana et.al. (1993); McFadyen and Skarratt (1996); McWilliam (2000); Leslie and Spotila (2001), addressed the worldwide range of expansion and the large economic and ecological impact of this species. Mudgal et.al. (1997); Raizada (2006); Verma and Mishra (1992) studied the ecology and phenology of *Hyptis suaveolens*. Padalia, et.al. (2013), mapped the occurrence of *Hyptis Suaveolens* in lower shiwaliks and addressed about its severity.

Scott et.al. (2002); Guisan and Thuiller (2005) demonstrates the importance of species distribution modelling in ecology and biogeography. Stolhgren et.al. (2010), advocates about the role of species distribution modelling in risk assessment and conservation. Guisan and Zimmermann (2000), describes variety of species distribution modelling methods that are available to predict potential suitable habitat for a species. In present study four different modelling approaches were used i.e. MaxENT, GARP, BIOCLIM and Ensemble model. MaxENT (Maximum Entropy) is a maximum entropy based machine learning program that estimates the probability distribution for a species' occurrence based on environmental constraints (Phillips et.al. 2006), and has been found to perform best among many different modelling methods (Elith et.al. 2006 and Ortega-Huertaand Peterson 2008). It requires only presence data and remains effective despite small sample sizes (Pearson et.al. 2007 and Benito et.al. 2009). GARP (Genetic Algorithm for Rule-set Production) is a genetic algorithm that creates an ecological niche model for a species that represents the environmental conditions where that species would be able to maintain populations (Stockwell 1999). BIOCLIM finds a single rule that identifies all areas with a similar climate to the locations of the species (Busby 1991).Ensemble model is simply a model which involves combining model outputs from different models (Stohlgren et.al. 2010) and is reported to outperformed than other individual models (Crossman and Bass 2009).

Related species distribution modelling studies in the past have been carried out *i.e.* Barbosa et.al. (2012), conducted a scientometric analysis to determine the main trends and gaps of studies on the use of ecological niche models (ENMs) to predict the distribution of invasive species. Jimenez-Valverde et.al. (2011), studied Use of niche models in invasive species risk assessments. Peterson and Vieglais (2001), carried out ecological niche modelling and addressed the challenges faced in predicting potential species invasions. Peterson et.al. (2003), studied Ecological niche modelling and predicted the potential invasive distributions of four alien plant species (garlic mustard, sericea lespedeza, Russian olive, and hydrilla) in North America. Gallien et.al. (2012), studied a novel methodological framework for improving the regional modelling of invasive species, where the use of a global model output to weight pseudo-absences in a regional model significantly improved the predictive performance of regional SDMs (Species Distribution Models). Braun (2007), predicted the future distribution of three pairs of exotic plant species in Florida using the species distribution model OM-GARP. Phillips et.al. (2004), studied and compared MAXENT with a standard distribution-modelling tool, called GARP. Stockwell (1999), studied problems and solutions to automated spatial prediction. Wilson et.al. (2005), used logistic regression to model the distribution of four plant species. Elith (2009), studied various species distribution modelling approaches and their predictive performance across space and time. Barbosa et.al. (2012), demonstrated the use of ecological niche models to predict the distribution of invasive species.

The impact of climate change on potential distribution of invasive has been studied at global, continental and country level using projected future climate scenarios. Broennimann and Guisan, (2008), predicted both present and future biological invasions in native as well as invaded ranges. They proposed an alternative approach of prediction that involves fitting models with pooled data from all ranges and concluded that pooled approach improves prediction of the extent of invasion. Taylor et.al. (2012), used CLIMEX model to estimate potential distribution of *Lantana camara* under current and future climate scenarios of A1B and A2 for year 2030 and 2070. Adhikari and Barik (2012), used HADCAM3 model to estimate potential distribution of *Cromolaena odorata* with respect to climate change over Indian sub-continent in 2020 A2 and B2 and 2080 A2 and B2 scenarios.

Ensemble models are models that are produced from combining outputs from different individual species distribution models. They are created by some preselective algorithm. Such selective algorithms are based on various approaches such as PCA (Thuiller 2004; Araújo et.al. 2005) and statistical criteria (Johnson and Omland 2004), or on basic mathematical functions such as averages and medians of ensembles of predictions (Gregory et.al. 2001; Araújo and New 2007). Araujo (2006), advocated the use of multiple models within an ensemble forecasting framework and described alternative approaches for the analysis of bioclimatic ensembles and stressed upon the improved accuracy by ensemble forecasts. Stohlgren et.al. (2010), carried out ensemble habitat mapping of invasive plant species and concluded that ensemble models may be useful in risk analysis of harmful invasive species. Poulos et.al. (2011), performed ensemble forecasting of potential habitat for three invasive species. Marmion et.al. (2009), evaluated consensus/ensemble methods in predictive distribution modelling.

It is very essential to assess the risk associated with invasive species and prioritize the risk zones for better management and conservation purposes. Mckenney et.al. (2003), assessed opportunities for improved risk assessments of exotic species in Canada using bioclimatic modelling.. Leung and Dudgeon (2008), studied ecological risk assessment and management of exotic organisms. They also studied ERA (Ecological Risk Assessment) techniques both qualitative and quantitative associated with exotic species. Foxcroft et.al. (2006), developed a framework to assess the risk associated with Riparian Plant Invasions into Protected Areas. Benke et.al. (2010), used a weight-assignment methodology based on multi-criteria decision analysis (MCDA), for risk assessment and zonation for invasive plant species.

3 Study Area

3.1 Geographic Location

The study area of this research study is a part of lower Himalaya and its foothills in the Darjeeling region (figure 1) which lies 87°59'2.6"E - 88°53'18"E to 27°14'1.0"N - 26°27'7.2"N including Himalayan parts of Sikkim, Nepal, Bhutan and Bangladesh encompassing an area of 8811.56 Sq.Kms.

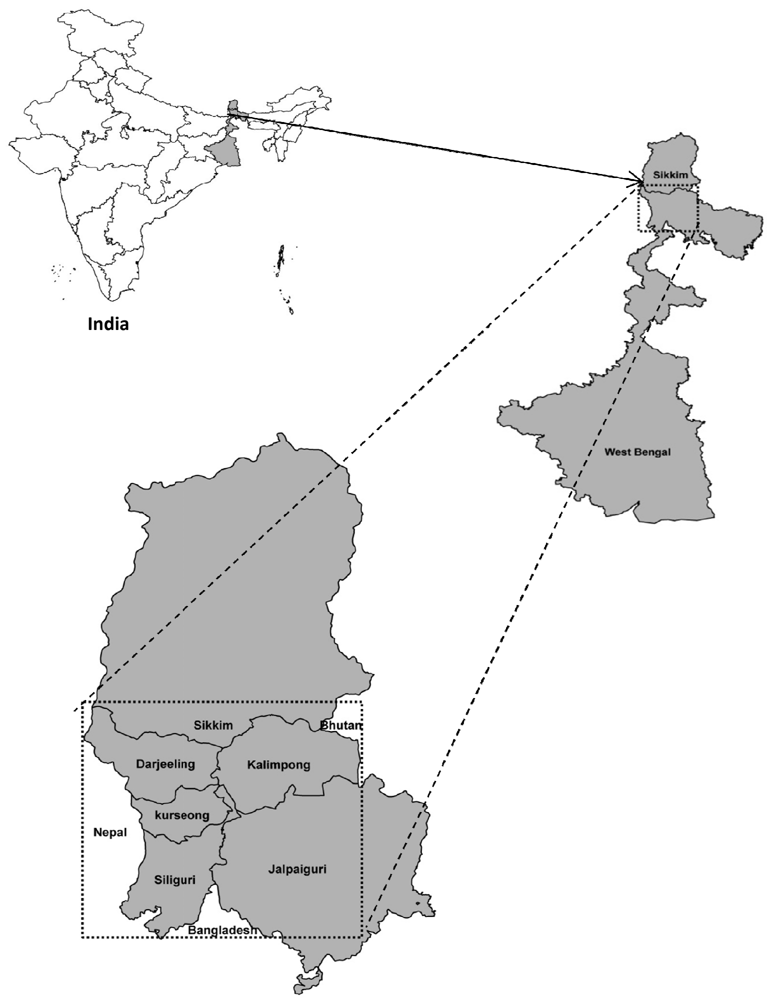

Figure 1 : Study area (Darjeeling Himalaya)

3.2 Physiography

The hill areas of Darjeeling District are located within the lesser and Sub - Himalayan belts of the Eastern Himalayas. The relief varies from 100 Mts. above sea level to the mighty Kanchenjunga, (8,598 m). The area is bounded by the Sikkim Himalaya in the north, the Bhutan Himalaya in the east and Nepal Himalaya in the west. The southern foothill belt is demarcated by a highly dissipated platform of terrace deposits extending along the east west axis. The inner belt is defined by a ridgeline stretching from the Darjeeling Hill to the west and Kalimpong Hill to the east, overlooking the southerly flowing Tista valley in between. Prominent rivulets contributing to the Rammam - Rangit basin, dissipate the northern slope of Darjeeling Hills. The major river of this reion are Tista, Great Rangit, Mechi, Balason, Mahananda, Lish, Gish, Chel,Ramman, Murti and Jaldhaka.

3.3 Climate

The orographic factor; cause the vertical zonation of temperature and decline of precipitation. Thus the mountain front is exposed to heavy rainfall, especially the middle parts of the southern hills. The mean annual temperature fluctuate from 24ºC in the plains and drops below 12ºC on the ridge. During summer month the temperature reaches 16º C - 17º C on the ridge and during winter drops at 5ºC-6ºC. The southern slopes of the ridges get much higher (4000-5000 mm) precipitation than the leeward sides (2000-2500 mm). The next main ridge with Tiger Hill gets 3000 mm while to the north the Great Rangit valley receives about 2000 mm of rainfall. The annual total rainfall in Darjeeling town fluctuates between 1870-3690 mm.

3.4 Geology and Soil

The Darjeeling Hill area represents a unique geo- environmental perception. The area of study is primarily composed of erosional landforms produced by southerly flowing streams, which have exposed a full cross section of different tectonic units. The form units are, however approximately the same throughout the hill area, having more or less uniform lithology, structure, climate, soil and vegetative covers. According to Mallet (1875), Audent (1935) the tectonic units are found to be in the reverse order of stratigraphic superimposition, and is represented by Siwalik and Gondwana systems. Towards the inner Himalayas, the thrusted sheets of Daling and Darjeeling group of crystalline rocks succeed these. The contact between different groups of rocks is represented by thrusts, dipping at high angles towards north.

The soil of the upland is usually red and gritty while that of the plains is dark and more fertile. Red and yellow soils have developed on the gneisses and schist's in the higher slopes of the Darjeeling Himalaya. The soil everywhere is residual, *i.e.*, derived by the weathering of the underlying rocks .The basic soil types are yellow soils, red brown soils and brown forest soils.

3.5 Flora

Darjeeling hill areas are unique from environmental Eco-perception. It is a biodiversity rich area endowed with abundance of rhododendrons, orchids, ferns, bryophytes, lichens besides tree species like cryptomeria terminalia, birches, acers, betulas quercus, machilus, elaeocerpus, pines, oaks, laurel, bamboos, hedychiums etc are found to grow in the hills.. Area is highly rich in endemicity, of the gymnosperms, 15 species occur in Eastern Himalayas with at least 5 genera being confined to the region.

The major portions of the forests in Darjeeling Himalayas are today found at elevations of 2000 mts and above. The area located in between 1000-2000 mts is cleared either for tea plantation or cultivation. The major forest types according to altitudinal variation found in Darjeeling Hill Areas are:

- Tropical moist deciduous forest (300-1000mts)
- Tropical evergreen lower montane forest (1000-2000mts.)
- Tropical evergreen upper montane forest (2000-3000mts.)
- Temperate forest (3000-3500mts.)
- Sub temperate forest (above 3500mts.)

3.6 Fauna

The study area covers 3 National Parks and 7 Wildlife sanctuaries i.e. Singalilia NP, Neora Valley NP, Gorumara NP, Jorepokhri Salamander WLS, Senchal WLS, Mahananda WLS, Chapramari WLS, Pangolakha WLS, Barsay WLS, and Kitam WLS. There are different climatic zones with distinctive attributes which favours a great fauna diversity to thrive and sustain. It hosts two of the world's rarest animals, the Himalayan Red Panda and the elusive Snow Leopard. Besides these its servers as a natural abode for animals like clouded leopard, common leopard, blue sheep, wild cats, tigers, bears, barking deer, sambhurs and the very rare pangolins. Birds like Yellow-billed Blue Magpai, Red tailed Minla, Maroon backed Accentor. Red headed Bullfinch, Satyr Tragopan, and the rare Broad Billed Warbler, Hill partridge, Kalij Pheasant, Large Hawk, Oriental and Lesser Cuckoos, Spot bellied eagle owl, Himalayan swift let, Darjeeling Woodpecker, various Babblers, and other colorful species are also found.

3.7 Socio Economic Condition

The total population is 132,016 and density is 12,000/km2. The hill population comprises mainly ethnic Nepalis who had migrated there during British rule, the plains harboured a large ethnic Bengali population who were refugees from the Partition of India. The principal economy of Darjeeling Hill Area depends on tea production, horticulture, agriculture and forestry. Darjeeling produces 7% of India's tea output, approximately 9,000,000 kilograms every year Besides tea, the most widely cultivated crops include maize, millets, paddy, cardamom, potato and ginger. Darjeeling has seen a significant growth in its population, its decadal growth rate being 47% between 1991 and 2001The colonial town had been designed for a population of only 10,000, and subsequent growth has created extensive infrastructural and environmental problems. The district's forests and other natural wealth have been adversely affected by an ever-growing population. Environmental degradation, including denudation of the surrounding hills has adversely affected the area.

3.8 List of photos describing the habit and habitat of selected invasive species from the study area.

Photo1: *Chromolaena odorata* in Sal forest at 300 altitude.

Photo2: Tea garden and forest edges holds threat of invasion by *Chromolaena odorata*

Photo3: *Yushania mailing* at 2600 altitude in senchal wildlife sanctuary.

Photo4: Temperate Grasslands, under high risk of invasion by *Yushania mailing*.

Photo5: Heavy infestation of *Hyptis suaveolens* along the dry river bed in sukna at 170 altitude.

Photo6: Riverrine areas, ideal habitat for Potent invader *Hyptis suaveolens*.

4 Materials and Methods

4.1 Materials

4.1.1 Satellite Data

- Landsat-TM (March and November 2010)
- ASTER DEM
- Google Earth images (2012)
- Climatic layers for Current and future HADCM3 2050 A2A and B2A scenarios from WORLDCLIM (http://worldclim.org/bioclim.htm).

4.1.2 Ancillary data

- Ground truth
- Topographic maps (78A/4 , 78A/8, 78A/12, 78A/16, 78B/1, 78B/2, 78B/3, 78B/5, 78B/6, 78B/7 and 78B/9 on 1; 50,000 scale)

4.1.3 Software

- ArcGIS v 9.3
- MAXENT v 3.2 (Maximum Entropy)
- Erdas Imagine v 9.3
- DIVA-GIS v 5.2
- GARP v 0.5 (Genetic Algorithm for Rule Set Prediction)
- BIOCLIM v 5.1
- SPSS v 16.0

4.1.4 Instruments

- Global Positioning System (Trimble Juno SB)
- Magnetic Compass.

4.2 Methods

4.2.1 Field Survey

The field visit to the study area (Darjeeling Himalaya) was carried out during the post monsoon period (September -October, 2012). In order to systematize data collection on the presence of selected invasive species, a grid based sampling design was adopted. The type of sampling was systematic. The individual grid size was of 1 km X 1 km in size. Within each grid, only one record (presence) was collected using GPS. The occurrence records were selected for three invasive species i.e. *Yushania mailing* (59 records), *Eupatorium odoratum* (89 records), and *Hyptis suaveolens* (48 records).

4.2.2 Preparation of environmental (bioclimatic) variables database:

The global climate data on monthly basis for maximum and minimum temperature and precipitation for the current as well as for HADCM3 based A2a and B2a 2050 scenario was downloaded from World Climatic Research Centre (Hijmans et al., 2005; http://worldclim.org/bioclim.htm). Using this data, nineteen bioclimatic variables, that are biologically significant to define eco-physiological tolerances of a species, were derived each for present and future scenarios through DivaGIS software.The derived nineteen bioclimatic variables which were used for modelling species ecological niche are as mentioned below.

BIO1 = Annual Mean Temperature
BIO2 = Mean Diurnal Range
BIO3 = Isothermality
BIO4 = Temperature Seasonality
BIO5 = Max Temperature of Warmest Month
BIO6 = Min Temperature of Coldest Month
BIO7 = Temperature Annual Range
BIO8 = Mean Temperature of Wettest Quarter
BIO9 = Mean Temperature of Driest Quarter
BIO10 = Mean Temperature of Warmest Quarter
BIO11 = Mean Temperature of Coldest Quarter
BIO12 = Annual Precipitation
BIO13 = Precipitation of Wettest Month
BIO14 = Precipitation of Driest Month
BIO15 = Precipitation Seasonality

BIO16 = Precipitation of Wettest Quarter
BIO17 = Precipitation of Driest Quarter
BIO18 = Precipitation of Warmest Quarter
BIO19 = Precipitation of Coldest Quarter

In addition to climatic variables, land use land cover and topographic variables (Slope, Aspect and Elevation) were also considered for modelling .Topographic variables were derived from Geo TOPO DEM (http:/gsi.go.jp). The environmental layer tiles were available at ~ 1 km^2 resolution. The geographic dimensions of environmental layers for the study area and pixel size was made uniform using spatial analyst tool in ArcGIS ver. 9.3.

Out of twenty four (19 climatic, 3 topographic and land use land cover) variables few significant variables were selected for each invasive species considering their importance in the model, co-linearity among the variables, and their biological significance for the particular species. To obtain a set of functionally relevant predictor environmental variables, all twenty four environmental variables were feed to Maxent model alongwith species occurrence records and variables with higher maximum entropy gains (percent contribution) were retained. Further exclusion of the variables was carried out by examining co-linearity among the variables. Among the two highly cross-correlated variables (pearson correlation coefficient $r>0.90$), one was chosen considering its biological relevance to the species, and ease of interpretation for inclusion in the model (Kumar and Stohlgren, 2009). For example, if annual temperature and temperature seasonality were highly correlated, we kept temperature seasonality since it captured a seasonal variability in temperature. Resultantly, 7 significant environmental variables were selected for modelling potential habitat suitability of *Yushania mailing,* 10 variables for *Chromolaena odorata* and 10 environmental variables for *Hyptis suaveolens*

The bioclimatic variables selected for modelling ecological niches of different invasive species are as mentioned below.

Table 1 : Selected environmental variables for habitat suitability modelling of individual selected invasive species

Yushania mailing	*Chromolaena odorata*	*Hyptis suaveolens*
DEM	Isothermality	Mean Diurnal Range
Max Temperature of Warmest Month	Slope	Isothermality
Min Temperature of Coldest Month	Precipitation of Warmest Quarter	DEM
Isothermality	Precipitation Seasonality	Slope
Precipitation of Driest Quarter	Temperature Seasonality	Temperature Seasonality
Precipitation Seasonality	Aspect	Annual Precipitation
Slope	Precipitation of Driest Quarter	Precipitation of Driest Month
	Precipitation of Coldest Quarter	Aspect
	Mean Diurnal Range	Max Temperature of Warmest Month
	LULC	Precipitation of Warmest Quarter

4.2.3 Land use Land cover:

Satellite image of Landsat TM for 2010 was downloaded from USGS website. Landsat TM data is orthorectifiezd so only haze removal was carried out. A general land use land cover map of study area delineating classes such as temperate conifer, moist deciduous, broad leaved mixed, sal, agriculture, grasslands and river bed was prepared using on-screen visual interpretation techniques at a scale of 1:90000.

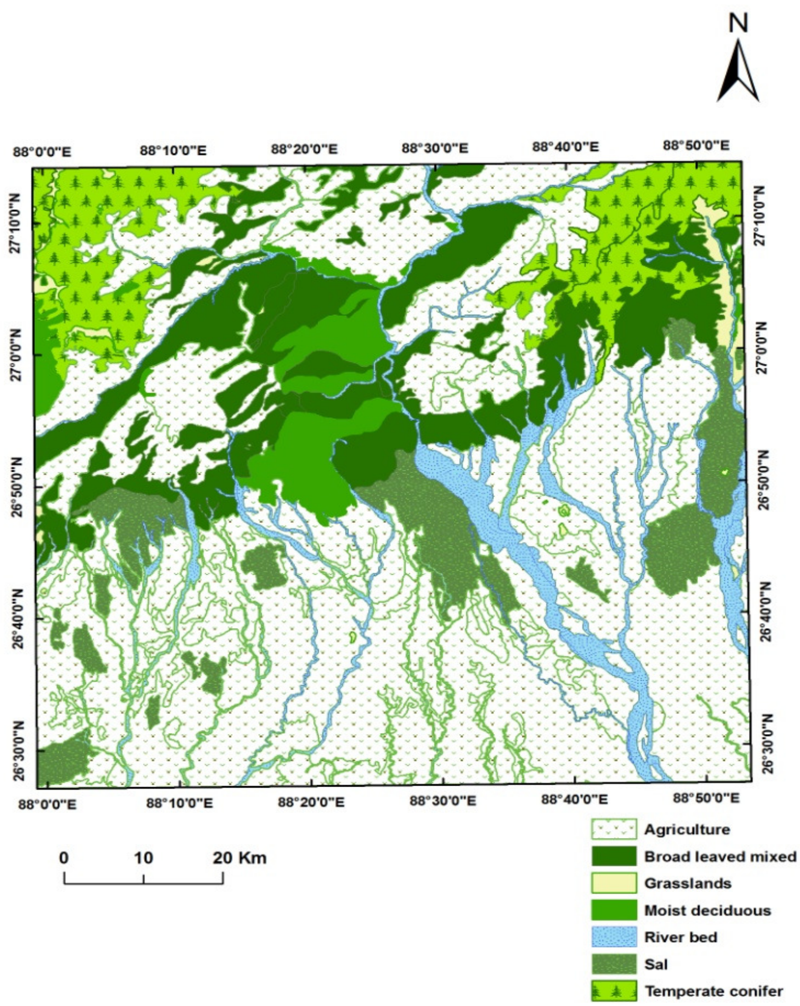

Figure 2 : Land Use Land Cover of Darjeeling Himalaya, 2010

4.2.4 Models Description:

We used three well-known species distribution modelling methods for presence-only data to produce ensemble prediction maps for each species for present scenarios. We also modelled future distribution of selected invasive species under HADCM3 A2a and B2a, 2050 climate change scenarios using Maxent modelling approach. Maximum entropy (Maxent) (Phillips et.al. 2006; Phillips and Dudík 2008), GARP (Stockwell 1999), and BIOCLIM (Nix 1986), were chosen for inclusion based on their good performance with presence-only data and because they differ both conceptually and statistically (Elith et.al. 2006; Kelly et.al. 2008). Maxent was run using the Maxent software for species habitat modelling v 3.3.3e (Phillips et.al. 2006). GARP was run using GARP v 0.5(Stockwell 1999), and BIOCLIM was run using BIOCLIM v 5.1Software (Martin 1996). Maxent uses a deterministic algorithm that finds the optimal probability distribution (potential distribution) of a species across a study area based on a set of environmental constraints. Maxent determines the best potential distribution by selecting the most uniform distribution subject to the constraint that each environmental variable in the modelled distribution matches its empirical average over the known distributional data (i.e. presence data). Maxent is sensitive to sampling biases in clustered or disparate datasets such as the ones included in this study.

Genetic algorithm for rule-set prediction (GARP) is an artificial intelligence based super-algorithm which uses other techniques (e.g., logistic regression, bioclimatic envelope, etc.) in a dynamic machine-learning environment (Stockwell and Peterson 2002; Anderson et.al. 2003). GARP uses species presence records and geo-referenced data on ecological factors to produce a model of species' ecological niches. The software is tailored to search for non-random correlations between species presence and absence and environmental characteristics using several different types of rules. GARP works in an iterative process of rule selection, evaluation, testing and incorporation or rejections to produce a heterogeneous rule set summarizing species' ecological requirements (Anderson et.al. 2002a). The algorithm can run several thousand iterations. GARP primarily works on presence data points, but it allows for resampling with replacement from the pixels without confirmed presence data in the training set to create a set of pseudo-absence points (Anderson et.al. 2003). When projected onto a geographical space, GARP provides predictions of the species' geographical distribution. GARP has been used extensively used for species distribution modeling (Peterson 2001; Anderson et.al. 2002a; Peterson et.al. 2002b; Stockwell and Peterson 2002).

BIOCLIM Implements the Bioclimatic Envelope Algorithm. The program interpolates a species bioclimatic envelope, which is a summary of the climate at locations from where the species has been recorded. BIOCLIM is a range-based model that describes a species climatic envelope as a rectilinear volume, that is, it suggests that a species can tolerate locations where values of all climatic parameters fit within the extreme values determined by the set of known locations (Carpenter et.al. 1993).For each given environmental variable the algorithm finds the mean and standard deviation (assuming normal distribution) associated to the occurrence points. Each variable has its own envelope represented by the interval [m - c*s, m + c*s], where 'm' is the mean; 'c' is the cutoff input parameter; and 's' is the standard deviation. Besides the envelope, each environmental variable has additional upper and lower limits taken from the maximum and minimum values related to the set of occurrence points. In this model, any point can be classified as: Suitable: if all associated environmental values fall within the calculated envelopes; Marginal: if one or more associated environmental value falls outside the calculated envelope, but still within the upper and lower limits. Unsuitable: if one or more associated environmental value falls outside the upper and lower limits. BIOCLIM'S categorical output is mapped to probabilities of 1.0, 0.5 and 0.0 respectively.

4.2.5 Sample size:

Literature claims that no algorithm can model extremely sparse species data successfully with few records the best that can be done is identification of the strongest environmental gradient(s) or trend(s) (Barry and Elith 2006). To check this hypothesis we ran the species distribution model with varying number of sample records i.e. 20, 40, 60, 80 and 100 and checked their area under curve under receiver operating characteristic method. Our main motive behind this was to find the minimum number of samples required for precise species distribution modelling.

4.2.6 Model Development

4.2.6.1 Present Invasive species potential distribution prediction

Finally selected environmental variables for particular species, based on maximum entropy gains and co-linearity testing, qualified for inclusion in distribution modelling through MAXENT, GARP and BIOCLIM. The entire occurrence records i.e. *Yushania mailing* (59 records), *Chromolaena odorata* (89 records), and *Hyptis suaveolens* (48 records) were given input to MAXENT, GARP and BIOCLIM. We generated models using 75% randomly assigned occurrences as a training dataset with the remaining 25% used as test dataset. Auto feature limiting function was used to train Maxent model. A small value assigned to regularization multiplier leads to over-fitting of output distribution to given presence records that produce more localized output. But a model fitting so close to training data does not generalize well to independent test data. Hence, larger regularization multiplier will give a more spread out and less localized prediction. Initially, the multiplier value was set very small (e.g. 0.02) with default set of parameter to have a highly over-fit model. Subsequently, the multiplier value was increased to 1 and the modelled distribution and changes in AUC was analyzed. Logit rule was used to generate single binary predictions using GARP with default parameters values (0.01 convergence limit, and 1000 maximum iterations). BIOCLIM approach was used by keeping all the values default except convergence limit of 0.01 and 1000 iterations to get binary prediction maps of selected invasive species. Maxent modelled approach generated a continuous output i.e. pixel values ranging from 0 - 1 while GARP produced a discrete output consisting of 0 (unsuitable habitat) and 1(suitable habitat) values. BIOCLIM also produced a categorical output of 0 (unsuitable habitat), 0.5 (marginal suitability) and 1(high suitability).

The probability of habitat suitability of invasive species were modeled on a scale of 0 to 1 by Maxent and the probabilities were reclassified into four classes *viz.*, 0 - 2.5, 2.5 - 5.0, 5.0 - 7.5 and 7.5 – 1 for better understanding and visualization. The pixel values for the output generated by Maxent was again reclassified into two classes for comparison with other models i.e. 0.00 – 0.50 and 0.50 – 1.00. The value greater that 0.5 indicates areas with a high probability of habitat suitability for the species while values lower than 0.5 represents low probability of habitat suitability or the areas are not at all suitable. For GARP, BIOCLIM and ensemble modelling approaches the outputs of different invasive species were reclassified into two classes by selecting 0.5 thresholds i.e. 0.00 – 0.50 and 0.50 – 1.00.

4.2.6.2 Future Invasive species potential distribution prediction

The effect of global climate change on potential habitat suitabilty of selected invasive species species i.e. *Yushania mailing*, *Chromolaena odorata,* and *Hyptis suaveolens* was modelled for the projected HADCM3 A2a and B2a 2050 climate change scenarios. The current and future potential distribution ranges of selected invasive species were modelled with occurrence data, and significant bioclimatic environmental predictors using a novel approach based on maximum entropy gain. MAXENT model for future A2a and B2a 2050 scenarios were trained with convergence limit of 0.01 and 1000 iterations using auto feature limiting function. The modeled distribution and changes in AUC were analyzed to set an appropriate multiplier value for proper model fitting. The model outputs were generated with output pixel value ranging from 0 - 1. The output pixel value was further reclassified into 4 categorical classes i.e. 0.00 – 0.25, 0.25 – 0.50, 0.50 – 0.75, 0.75 – 1.00 for better understanding and visualization.

4.2.7 Sensitivity Analysis

A jack-knife procedure was used to evaluate the relative importance of each predictor variable and the ability to correctly predict new ranges in the model. The Jackknifing calculates the training gain of each variable if the model was run in isolation, and compares it to the training gain with all the variables. This is useful to identify which variables contribute the most individually.

4.2.8 Evaluation of models

The evaluation of the accuracies of prediction models generated through Maxent, GARP and BIOCLIM was carried out selecting threshold independent receiver operating characteristic (ROC) area under curve (AUC) method. AUC is a widely used procedure for comparing species distribution model performance. The ROC curve would be defined by plotting sensitivity against '1 – specificity' across the range of possible thresholds Sensitivity and specificity are used because these two measures take into account all four elements of the confusion matrix (true and false presences and absences). The ROC curve describes the relationship between the proportion of observed presences correctly predicted (sensitivity) and the proportion of observed absences incorrectly predicted (1 – specificity). A high AUC score reflects that the model can discriminate accurately between locations at which the species is present or absent. The AUC measures model performance that ranges from 0 to 1. A model performs well when the AUC is large. Usually, AUC values of >0.9 indicate high accuracy, values of 0.70 – 0.9 indicate good accuracy, and values 0.5 (random) to 0.7 indicate low accuracy.

4.2.9 Ensemble modelling

Ensemble maps were produced by combining the binary habitat maps from the three individual models, (Marmion et.al. 2009) for three individual invasive species. We used basic mathematical function i.e. Mean (all), (Araújo and New 2007) function for creating ensembles of predictions. In the predictive phase of modelling, each of the three modelling methods produced an output map of continuous values between zero and one corresponding to the probability that a pixel is suitable habitat for the species. To convert these continuous maps into binary (habitat versus non-habitat) maps, we needed to select a threshold such that probability values above that threshold were designated as habitat, while values at or below that threshold were designated as non-habitat. That is, we selected a threshold of 0.5, (Manel et.al. 1999; Hijmans and Graham 2006; Buckley et.al. 2010). Once the threshold was selected, the resulting ensemble map displayed in integer values, with the higher value of each pixel corresponding to the number of individual models that predict that pixel to be more suitable habitat This output can be considered a "vote" from the three modelling techniques. A score of zero indicates that none of the modelling techniques assigned that area as suitable habitat, while a higher value indicates that all modelling techniques assigned that area as suitable habitat. We reclassified the ensemble prediction map for the selected invasive species into binary classes of 0 (suitable) and 1(unsuitable) for better interpretation and understanding. The class 0 denotes that none of the model assigned the area as suitable habitat while the class 1 denotes that the selected modelling approaches gave their respective vote for assigning that area to be suitable for that particular invasive species.

4.2.10 Risk Zonation

Species distribution models describe the potential niches of the concerned species therefore they can be used for delineating/prioritizing risk zones at global or regional level. In order to give clearer picture of invasion risk, the studies should be carried out at local level by incorporating landscape structures, species richness and disturbance into consideration. In this study attempt has been made to prioritize/delineate risk zones at realized niche levels of the concerned species i.e. at the local level of the species occurrence using a novel multi criteria risk zonation approach. To delineate invasive species risk zones ensemble habitat suitability outputs for individual invasive species and risk determining factors like vegetation type, conservation status, species diversity and disturbance source (land use, road length) were considered. The grid of size 5 km * 5 km was overlaid on the ensemble habitat suitability outputs of respective invasive species and suitable areas for respective species were masked out. Within potential suitable areas of respective invasive species further attempt was made to find true invasive risk zone by incorporating localized invasion influencing factors. The concerned risk influencing factors i.e. vegetation type/ land use, within which four classes were there namely moist deciduous, sal, temperate conifer and broad-leaved mixed forests were given risk weightage depending on their cover area i.e. if their cover area is large then the invasion risk is low and vice- versa. Resultantly moist deciduous was categorized as high, sal and temperate conifer was categorized as medium and broad leaved mixed was classified as low. Presence of conservation status makes the risk more severe therefore National Parks and Wildlife Sanctuaries were given high risk weightage. Species diversity was calculated vegetation type wise and type having higher species diversity was given high weightage and vice- versa. Species diversity calculated for temperate conifer, broad leaved mixed, moist deciduous and sal was 3.1, 2.3, 3.3 and 2.6 respectively. Disturbance sources i.e. road networks length, which was found varying from 0 to 50 km's therefore it was classified into 0- 10 km's as low risk, 10- 20 km's as medium risk and > 20 as high risk. Within each grid the scores of concerned risk determining factors were calculated. A risk score key (Table 2) was prepared and a final risk weightage was given to a particular grid. The entire study area was prioritised/delineated into high, medium, low and no invasion risk zones. Table 3 defines the definitions and action needed based on final risk rating in the concerned risk scenarios.

Table 2 : Key for determination of the final risk score

Scenario	Vegetation type/ land use	Conservation status	Disturbance source	Vegetation type species richness	Risk Rating
1	H	H	H	H	H
2	H	H	H	M	H
3	M	H	M	H	H
4	M	H	M	M	M
5	M	H	H	M	H
6	M	H	L	M	M
7	L	H	H	L	H
8	L	H	H	M	H
9	M	H	L	L	M
10	L	L	L	L	L

Legend: Impact rating described as H – high; M – medium; L – low

Table 3 : Risk characterizations, definitions and recommended actions required based on the final risk rating

Risk Scenario	Definition	Action
No	Acceptable risk: organism(s) of little concern	1. Introduction may be permitted 2. No mitigation is required
Low and Medium	Unacceptable: organism(s) of moderate concern	1. Introduction should be banned or should be controlled via risk management 2. Mitigation is required
High	Unacceptable: organism(s) of high concern	1. Introduction should be banned. 2. Prevention rather than mitigation is mandated, and control measures should be considered.

The schematic diagram of the methodology followed is provided in Fig 3.

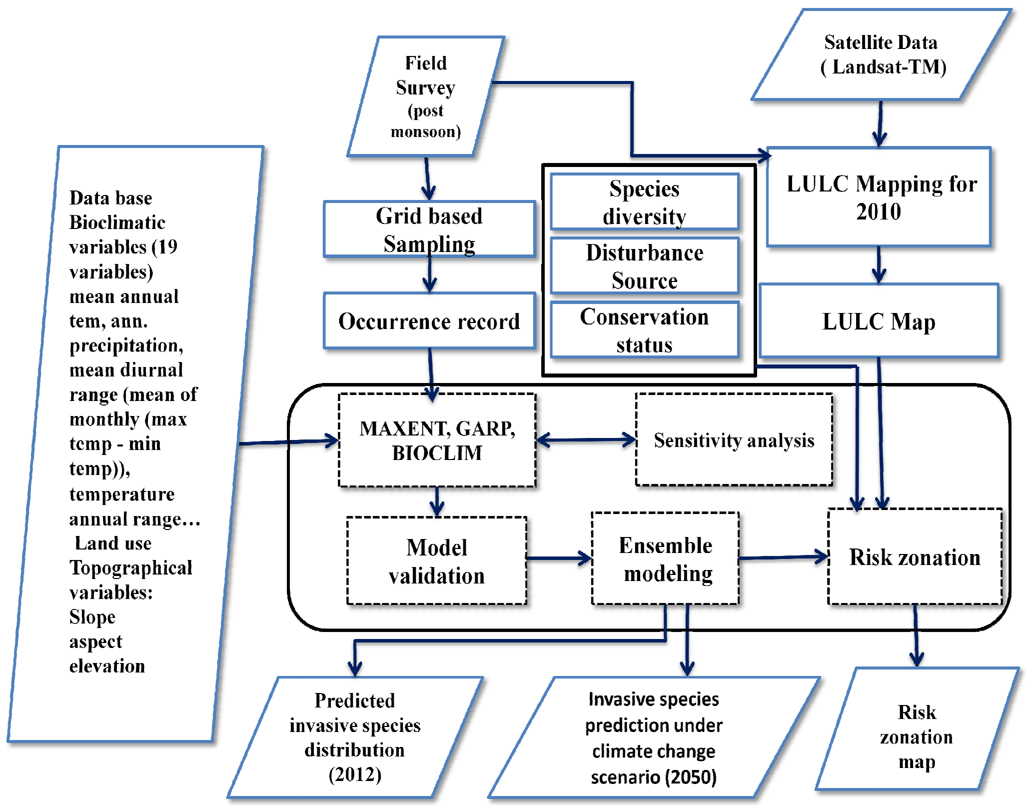

Figure 3 : Flow diagram of the methodology

5 Results and Discussion

5.1 Potential Invasive species distribution:

Figure 4, 5, 6 and 7 depicts the potential habitat suitability of *Yushania mailing* modelled using Maxent, GARP, BIOCLIM and ensemble modelling respectively.

The total suitable area calculated using Maxent was 1628 sq.km. The predicted main areas of potential habitat suitability of mailing bamboo lies in Darjeeling phulbazar, Jourbunglow, Sukiapokhri, Rangli Rangliot, Kalimpong parts of Darjeeling district and adjoining areas of Nepal, Bhutan and Sikkim. Field survey and modeled outputs indicates that high altitudes areas having elevation of 1600 to 3600 meters are suitable for mailing bamboo. Suitable habitat for mailing bamboo was modelled at a maximum elevation of 3600 meters at Nepal, adjoining to Darjeeling district and it was also predicted at 2800 meters towards adjoining Bhutan side. The modeled output shows temperate conifer and broad-leaved mixed forests as their preferred habitats. Protected areas like Singallila National Park, Barsay Wildlife Sanctuary, Neora valley National Park and Senchal Wildlife Sanctuary were found to be highly suitable for its habitat.

The total suitable area calculated using GARP was 2783 sq.km. GARP showed larger potential area in Kalimpong , Gorubathan, Bhutan, Mirik, Jourbungalow and Sukiapokhri as compared to Maxent and BIOCLIM.

BIOCLIM modeled 2037 sq.km as suitable. BIOCLIM showed increased area suitability in Sikkim and Mirik as compared to other models.

The habitat suitability area for mailing bamboo using ensemble modelling was calculated as 2819 sq.km.

Although individual models differed in their strength of predictions i.e AUC scores, the area predicted suitable by them matches with the species ecology and field survey. All the models varied in their prediction strength. Habitat suitability maps varied with individual models and species. The highly suitable areas (>0.5 probability) for mailing bamboo predicted by models co-relate well with the survey records.

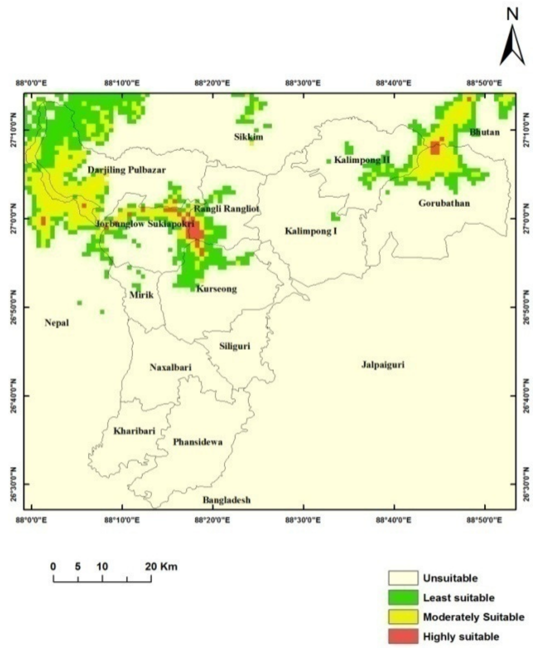

Figure 4 : Maxent modeling prediction for potential habitat suitability of Yushania mailing

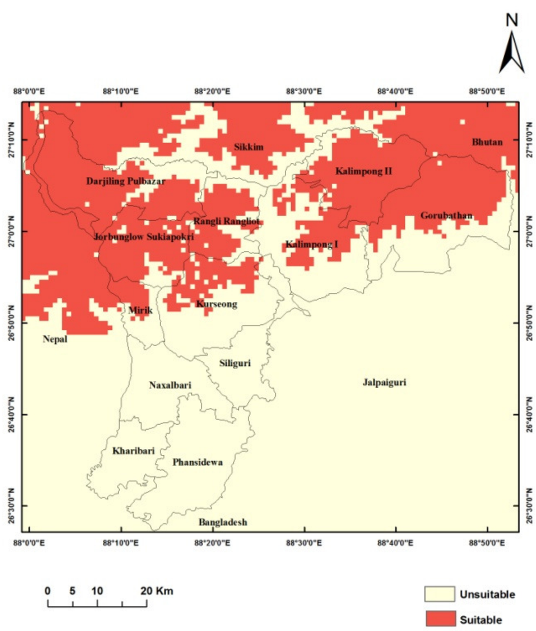

Figure 5 : GARP modelling prediction for Potential habitat suitability of *Yushania mailing*

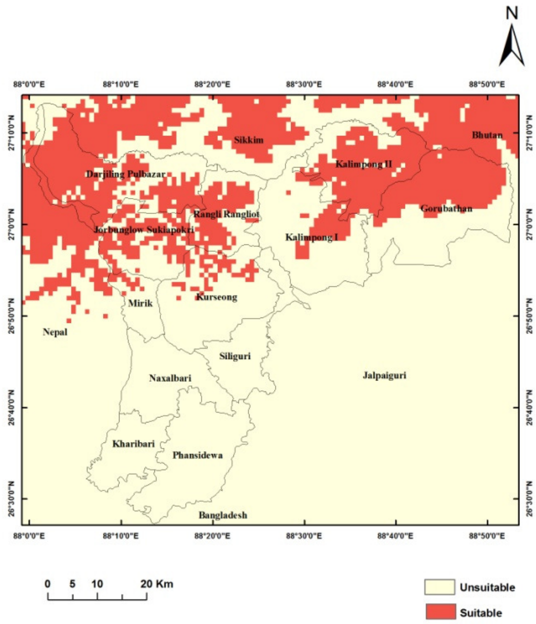

Figure 6 : BIOCLIM modelling prediction for potential habitat suitability of *Yushania mailing*

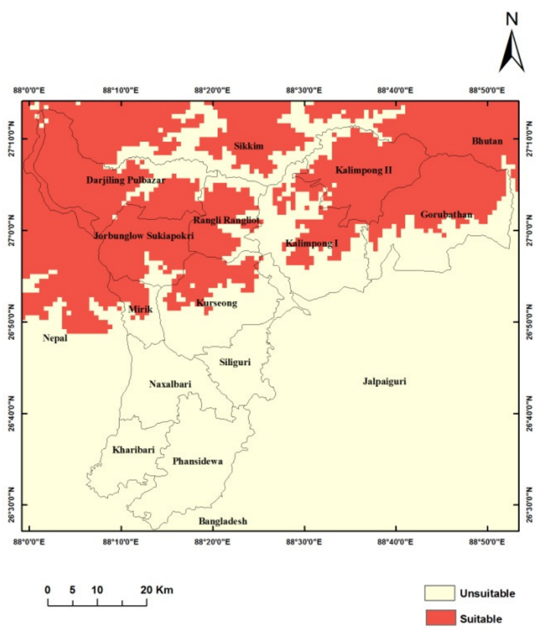

Figure 7 : Ensemble modelling prediction for Potential habitat suitability of *Yushania mailing*

Figure 8, 9, 10 and 11 illustrates the potential habitat suitability of *Chromolaena odorata* (syam weed) modeled using Maxent, GARP, BIOCLIM and ensemble models respectively.

The total suitable area calculated using Maxent was 2077sq.km. The predicted suitable areas of syam weed are very widespread, rising from low lying altitude of 160 meters to 1100 meters. Vegetation type's classes like moist deciduous, broad-leaved mixed forests, agriculture and river beds were modeled as its suitable habitat.Maxent modelled suitable areas were in Mirik, Kurseong, Siliguri, Kalimpong, and Rangli- rangliot parts of Darjeeling district,

GARP predicted 3220 sq.km. area as suitable. It modelled suitable area upto an elevation of 1600 meters encompassing adjoining areas of Bhutan and Jalpaiguri, Gorubathan, Mirik, Kurseong parts of Darjeeling district.

BIOCLIM predicted 2746 sq.km. as suitable area. It showed increased suitable area in parts of Kurseong and Mirik and decrease in parts of Jalpaiguri and Siliguri as compared to Maxent and GARP.

The ensemble model predicted 2263 sq.km. area as suitable. It provided average habitat suitability throughout the study area. Protected area i.e. Mahananda Wildlife Sanctuary was modeled as highly suitable habitat for *Chromolaena odorata*.

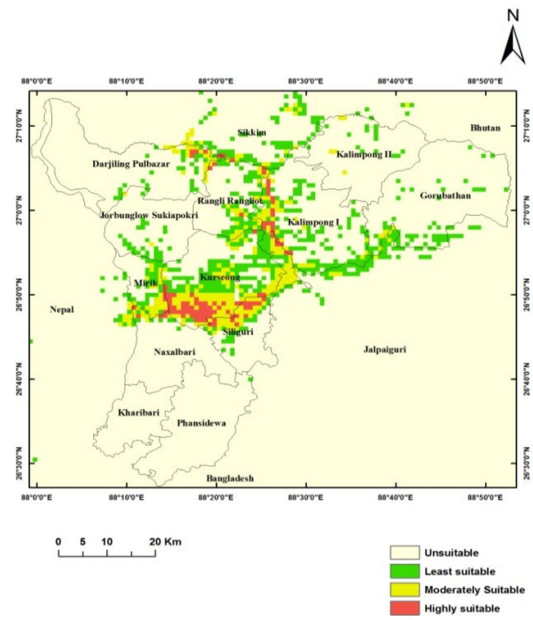

Figure 8 : Maxent modelling Prediction for Potential habitat Suitability of *Chromolaena odorata*

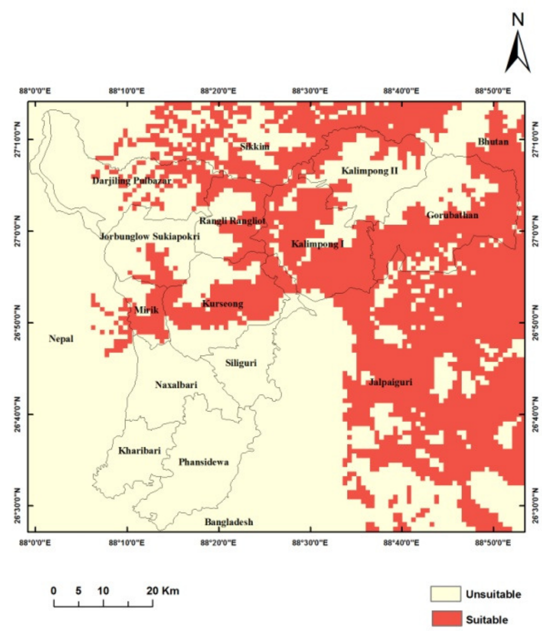

Figure 9 : GARP modelling prediction for potential habitat suitability of *Chromolaena odorata*

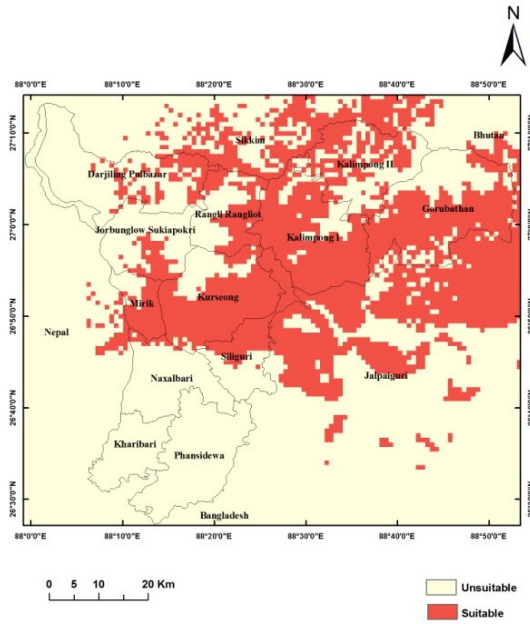

Figure 10 : BIOCLIM modelling prediction for potential habitat suitability of *Chromolaena odorata*

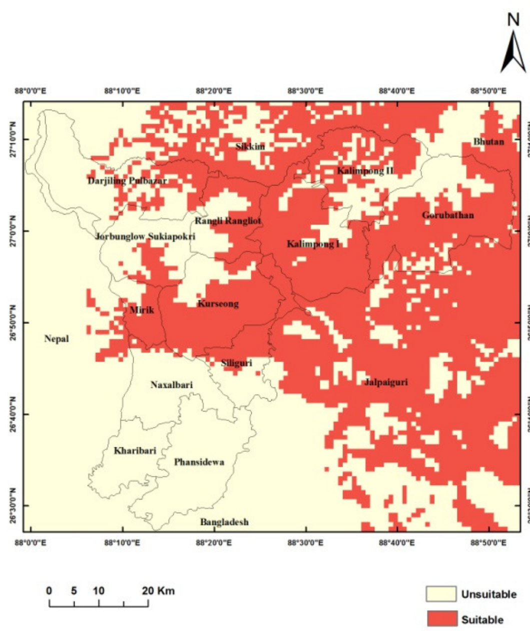

Figure 11 : Ensemble modelling prediction for potential habitat suitability of *Chromolaena odorata*

Figure 12, 13, 14 and 15 describes the potential habitat suitability of *Hyptis suaveolens* (bushmint), modeled using Maxent, GARP, BIOCLIM and ensemble models respectively.

The predicted suitable area of bushmint was 358 sq.km. modeled from Maxent. It was predicted at an elevation ranging from 100 to 400 meters. Suitable habitats were predicted in agriculture, and river beds. It was also predicted in open areas of moist deciduous and broad leaved mixed forest. Their distribution was predicted in riverine areas of Siliguri, Mirik, Naxalbari, Kurseong and Rangli- Rangliot.

GARP predicted 264 sq.km. as suitable area. It modelled less suitable area as compared to Maxent.

BIOCLIM modelled 388 sq.km. as suitable area. It showed shift towards eastern side i.e Jalpaiguri and Gorubathan.

Ensemble model predicted 406 sq.km. as suitable area. It showed average suitability from all three modeled outputs in low lying parts of Kurseong, Naxalbari, Jalpaiguri, Mirik and adjoining riverine areas of Nepal and Sikkim. Mahananda Wildlife Sanctuary was modeled as its suitable habitat.

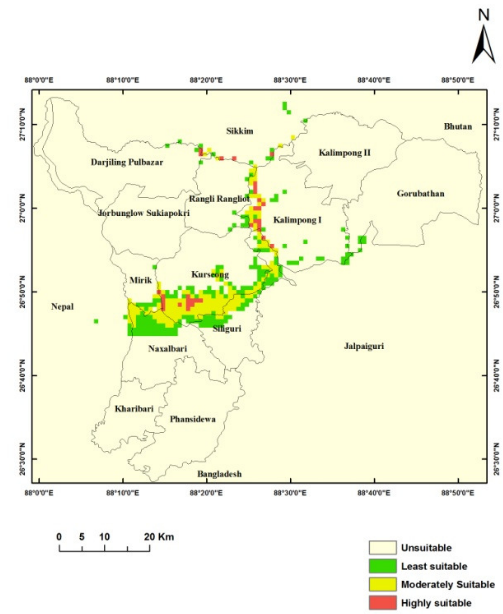

Figure 12 : Maxent modelling prediction for potential habitat suitability of *Hyptis suaveolens*

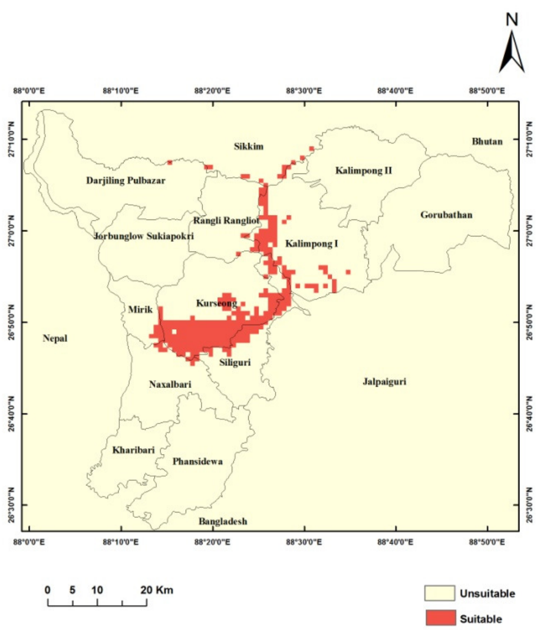

Figure 13 : GARP modelling prediction for potential habitat suitability of *Hyptis suaveolens*

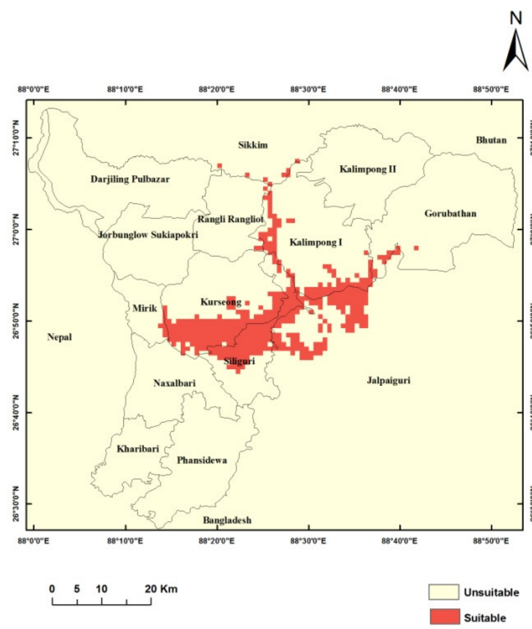

Figure 14 : BIOCLIM modelling prediction for potential habitat suitability of *Hyptis suaveolens*

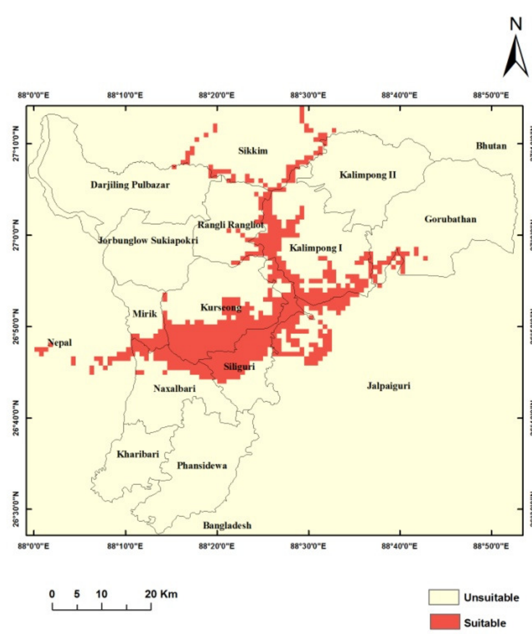

Figure 15 : Ensemble modelling prediction for potential habitat suitability of *Hyptis suaveolens*

5.2 Impact of climate change

Figure 16 and 17 shows the potential habitat suitability of *Yushania mailing,* modelled for the year 2050 under A2a and B2a climate change scenarios respectively.The results show expansion of least, moderate and highly habitat suitable area for *Yushania mailing* in A2a scenario as compared to that in B2a scenarios. Latitudinal expanse of suitable habitat potential distribution of mailing bamboo will occur in A2a scenario with respect to current potential distribution and B2a 2050 future scenario. There will be shrinkage of habitat suitability area for mailing bamboo in B2a scenario as compared to that of present and A2a scenarios. In A2a scenario suitable habitat will increase in areas of Darjeeling phulbazar, Sukiapokhri, Rangli-Rangliot, Kalimpong and adjoining areas of Nepal and Bhutan. Adjoining areas of Nepal and Bhutan were modeled as highly suitable areas for its spread under both the scenarios. Their suitable area was restricted to temperate conifer and broad- leaved mixed forests in both the scenarios. Protected areas i.e. Singallila National Park , Barsay Wildlife Sanctuary, Neora valley National Park and Senchal Wildlife Sanctuary were modeled as highly suitable areas under both climate change scenarios. Its suitable area was predicted within elevation range of 1600 – 3600 meters. Out of total study area of 8811 sq.km. the suitable area predicted by Maxent for A2a scenario is classified as least suitable (1195 sq.km), moderately suitable (447 sq.km), highly suitable (43 sq.km) i.e. a total suitability area of 1685 sq.km.and for B2a is least suitable (939sq.km), moderately suitable (302 sq.km), highly suitable (33 sq.km) i.e. a total suitability area of 1274 sq.km. It can be concluded that climate change will induce rise in least, moderately and highly habitat suitability area in A2a scenario. Potential suitable habitat of mailing bamboo will shrink in B2a scenario as compared to that with present and A2a scenarios.

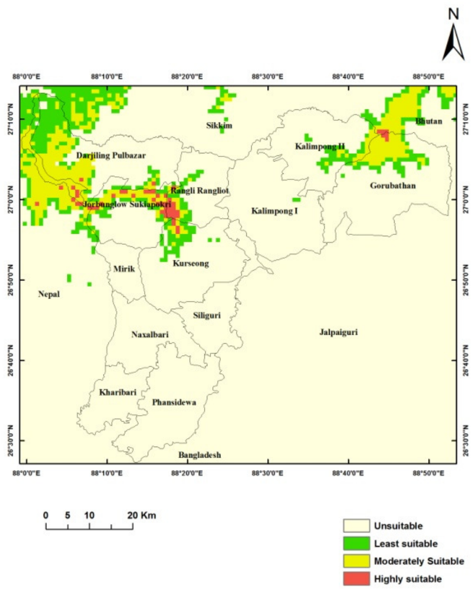

Figure 16 : Potential habitat suitability of *Yushania mailing* in A2a 2050 future climate scenario

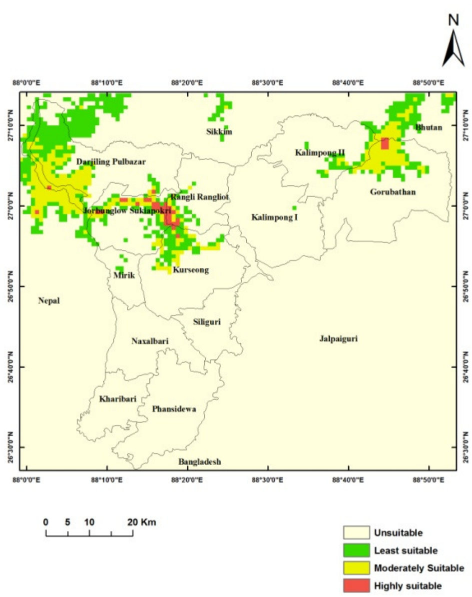

Figure 17 : Potential habitat suitability of *Yushania mailing* in B2a 2050 future climate scenario

Figure 18 and 19, shows the potential habitat suitability of *Chromolaena odorata* , modelled for the year 2050 under A2a and B2a climate change scenarios respectively. *Chromoleana odorata* shows drastic increase in least, moderate and highly potential habitat suitability area in B2a scenario. However in A2a scenario shrinkage is marked in habitat suitability area with respect to present and B2a scenarios. The suitable areas modelled for its habitat under A2a scenario were Mirik, Kurseong, Rangli-Rangliot, Kalimpong and Siliguri while under B2a scenario increase in suitable areas was modelled. Suitable area extended eastwards and westwards i.e. towards adjoining areas of Sikkim, Bhutan and Nepal. Agriculture, river bed, moist deciduous and broad-leaved mixed forests were modeled as its suitable habitat under both scenarios. The elevation range of suitable area was modeled between 160 meters to 1000 meters. The overall suitable area predicted for *Chromoleana odorata* by Maxent for A2a scenario is classified as least suitable (1635 sq.km), moderately suitable (250 sq.km), highly suitable (80 sq.km) i.e. a total suitability area of 1965 sq.km. and for B2a is least suitable (2602 sq.km), moderately suitable (364 sq.km), highly suitable (107 sq.km) i.e. a total suitable area of 3073 sq.km. It can be concluded that the potential suitable habitat of *Chromoleana odorata* will expand in B2a scenario vastly as compared to that of A2a and current scenarios.

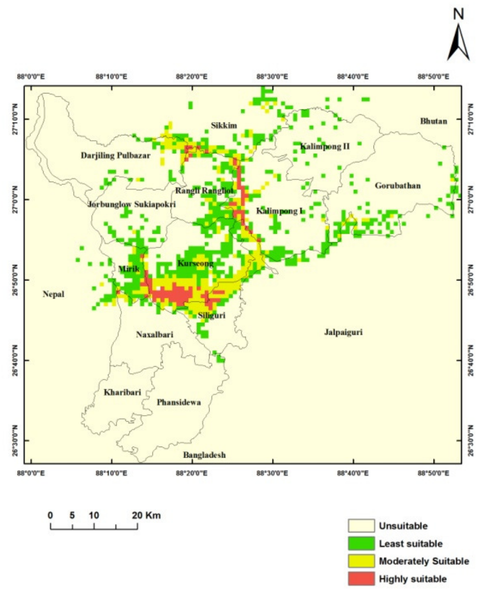

Figure 18 : Potential habitat suitability of *Chromolaena odorata* in A2a 2050 future climate scenario

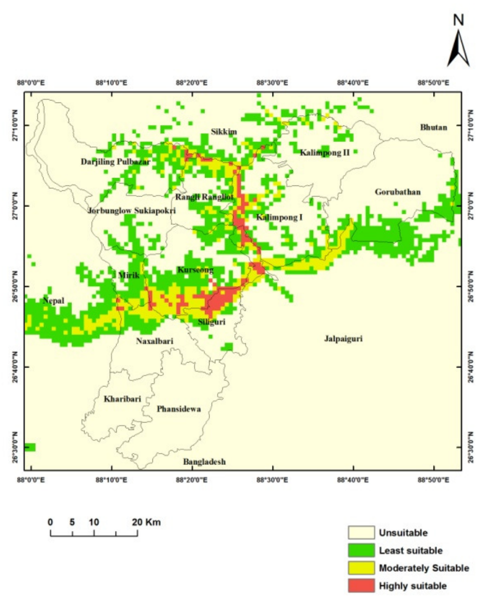

Figure 19 : Potential habitat suitability of *Chromolaena odorata* in B2a 2050 future climate scenario

Figure 20 and 21 shows the potential habitat suitability of *Hyptis suaveolens,* modelled for the year 2050 under A2a and B2a climate change scenarios respectively. A2a and B2a scenarios will not cause much alteration in potential habitat suitability area of *Hyptis suaveolens*. It will be almost same as the overall habitat suitable area predicted by them does not carry much variation within A2a and B2a scenarios. However results do show the translation of suitable areas from one class to another within the climate change scenarios. Increase in least suitable area was predicted in B2a scenario. There was also increase in moderately suitable area of bushmint in A2a scenario as compared to that of B2a scenario. There was a gentle increase in highly suitable area in B2a scenario, however the range shifts remains nominal under present and climate change scenarios. The suitable areas modeled for A2a scenarios are riverine and low lying areas of Mirik, Naxalbari, Kurseong, Siliguri, Rangli-Rangliot. In B2a scenarion the modelled area remains same except in Naxalbari area of Darjeeling district it is predicted to increase. The suitable area calculated as least suitable (135 sq.km), moderately suitable (152 sq.km), highly suitable (21 sq.km) i.e. a total suitable area of 305 sq.km and for B2a is least suitable (179 sq.km), moderately suitable (139 sq.km), and highly suitable (27sq.km) i.e. a total suitability area of 345 sq.km.

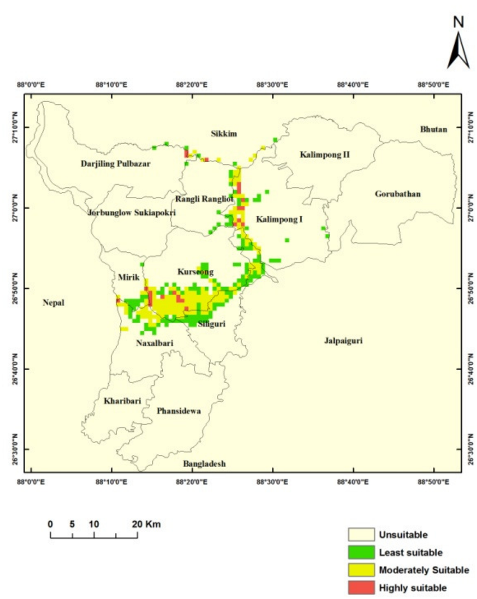

Figure 20 : Potential habitat suitability of
Hyptis suaveolens in A2a 2050 future climate scenario

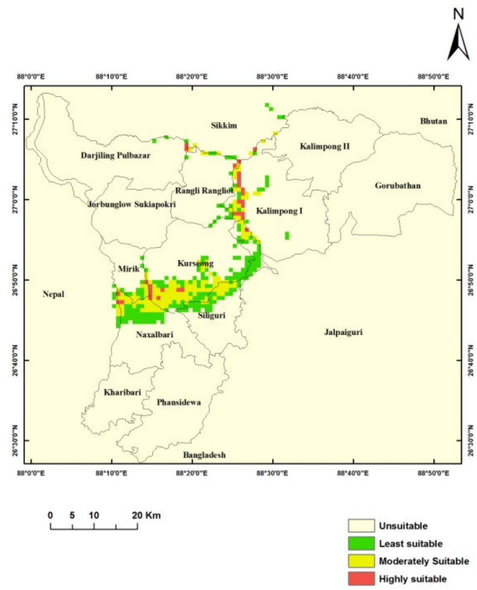

Figure 21 : Potential habitat suitability of *Hyptis suaveolens* in B2a 2050 future climate scenario

5.3 Evaluation of models

The results suggested that the Maxent modelled habitat suitability was in general consistent with those resulting from GARP, BIOCLIM and ensemble but the AUC predicted by Maxent was significantly higher than that of GARP and BIOCLIM predictions. The test AUC value across the 0.01 convergence and 1000 iterations of various models and species is illustrated in Table 4. This suggests that Maxent has better prediction accuracy as compared to GARP and BIOCLIM. AUC values were consistent in case of Maxent but not with GARP and BIOCLIM. Table 1 shows that though in all the cases the model values are highly significant, GARP and BIOCLIM has less area under curve suggesting weak predictions. Maxent has more area under curve at high significance level suggesting strong predictions.

Table 4 : Scores of AUC for different models and species

Model	Species	AUC
Maxent	Arundinaria mailing	0.95
Maxent	Hyptis suaveolens	0.98
Maxent	Chromolaena odorata	0.95
GARP	Arundinaria mailing	0.89
GARP	Hyptis suaveolens	0.90
GARP	Chromolaena odorata	0.74
BIOCLIM	Arundinaria mailing	0.71
BIOCLIM	Hyptis suaveolens	0.50
BIOCLIM	Chromolaena odorata	0.68

5.4 Number of samples required:

The number of records required depends on the complexity of the relationship between the species and its environment. In general, more records are better, because large data sets allow more subtle aspects of the response to environment to be modelled (Elith et.al. in press). In the past, statisticians have used as a rule of thumb for regression models (Harrell 2001), a requirement for at least 10 records to allow good estimation of each fitted parameter. Fewer data tend towards spurious over fitted models that can be highly imprecise and unreliable.

Interestingly number of samples did not played any significant effect on AUC (Table 4). When Maxent model was run with 20 samples the AUC was 0.97 subsequently AUC value of 0.98, 0.96, 0.95 and 0.95 was achieved with sample size of 40, 60, 80 and 100 (Figure 22) individuals respectively. It can be concluded that number of samples has little or no role in precise habitat modelling for invasive species rather their spatial distribution does contributes in predicting suitable habitat suitability distribution.

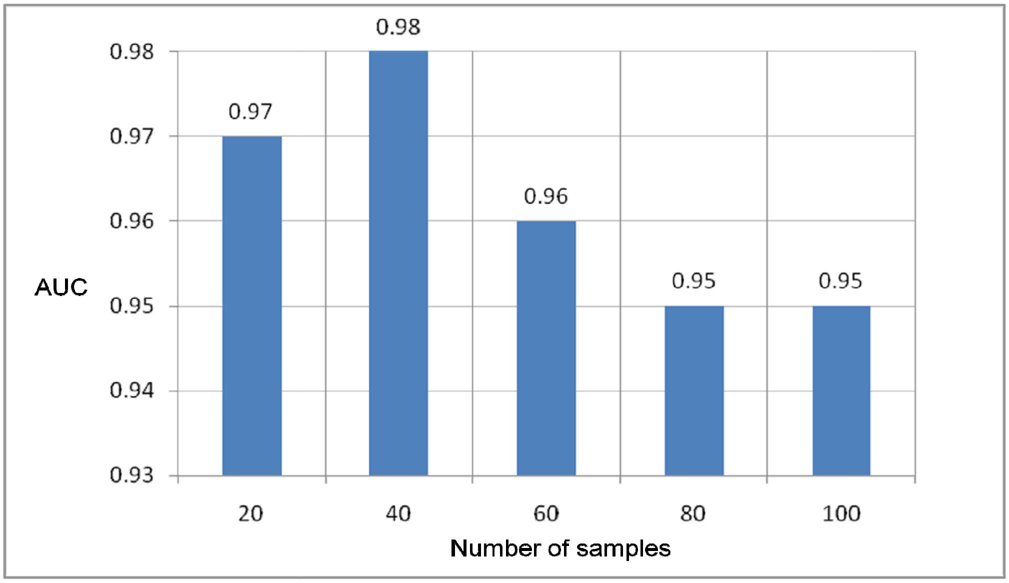

Figure 22 : Varying number of samples and their respective area under curve scores

5.5 Environmental variables:

Among all the 24 variables, variables (<1%) contribution were checked for co-linearity (Table 8) with one or other variables selected in the model. Among the highly cross-correlated variables (r>0.90), one was chosen considering its biological relevance to the species and ease of interpretation for inclusion in the model. For example, annual mean temperature was having less than 1 % contribution in the model and was also highly correlated with Max Temperature of Warmest Month, Mean Temperature of Coldest Quarter, Mean Temperature of Driest Quarter, Mean Temperature of Warmest Quarter and Min Temperature of Coldest Month and hence, it was excluded. Table 5, 6 and 7 illustrates the strength/contribution of each selected variable for *Yushania mailing, Chromolaena odorata* and *Hyptis suaveolens* respectively in describing their potential habitat suitability distribution.

Table 5: Variable contribution for *Yushania mailing*

Variable	Percent contribution
DEM	81.5
Max Temperature of Warmest Month	6.1
Min Temperature of Coldest Month	4.8
Isothermality	3.2
Precipitation of Driest Quarter	2.3
Precipitation Seasonality	1.2
Slope	1

Table 6 : Variable contribution for *Chromolaena odorata*

Variable	Percent contribution
Isothermality	31.4
Slope	19.2
Precipitation of Warmest Quarter	15.6
Precipitation Seasonality	13
Temperature Seasonality	8.9
Aspect	3.5
Precipitation of Driest Quarter	3.5
Precipitation of Coldest Quarter	2
Mean Diurnal Range	1.8
LULC	1

Table 7 : Variable contribution for *Hyptis suaveolens*

Variable	Percent contribution
Mean Diurnal Range	25.3
Isothermality	21.5
Dem	14.1
Slope	11.6
Temperature Seasonality	6.5
Annual Precipitation	6
Precipitation of Driest Month	4.4
Aspect	4.4
Max Temperature of Warmest Month	3.1
Precipitation of Warmest Quarter	3

Table 8 : Cross-correlations (Pearson correlation coefficient, r) among 24 bioclimatic and topographic variables performed using SPSS statistical software. Correlations values depicted with bold highlighted text indicate highly correlated variables

Variables	Aspect	DEM	Isothermality	LULC	Max Temperature of Warmest Month	Mean Diurnal Range	Mean Temperature of Coldest Quarter	Mean Temperature of Driest Quarter	Mean Temperature of Warmest Quarter	Mean Temperature of Wettest Quarter	Min Temperature of Coldest Month	Precipitation of Coldest Quarter	Precipitation of Driest Month	Precipitation of Driest Quarter	Precipitation of Warmest Quarter	Precipitation of Wettest Month	Precipitation of Wettest Quarter	Precipitation Seasonality	Slope	Temperature Annual Range
Temperature Seasonality	0.021	-0.05	0.24	0.119	0.225	0.67	-0.016	-0.01	0.1017	0.1	-0.23	-0.1	-0.02	-0.27	-0.51	-0.45	-0	-1	-0	0.7742
Annual Mean Temperature	-0.07	-0.99	0.75	0.348	0.983	0.717	0.998	1	0.9985	1	0.95	-0.9	-0.79	-0.86	0.58	0.59	0.6	0.6	-0.1	0.6342
Annual Precipitation	-0.06	-0.63	0.36	0.364	0.493	0.137	0.642	0.64	0.5914	0.59	0.68	-0.5	-0.58	-0.37	0.96	0.97	1	0.6	-0	0.0358
Aspect	0	0.028	-0.09	0.026	-0.07	-0.06	-0.071	-0.07	-0.068	-0.07	-0.07	0.04	0.059	0.031	-0.07	-0.06	-0	-0	0.1	-0.04
DEM	0	0	-0.74	-0.37	-0.97	-0.71	-0.987	-0.99	-0.988	-0.99	-0.93	0.92	0.802	0.863	-0.59	-0.61	-1	-1	0.1	-0.632
Isothermality	0	0	0	0.219	0.782	0.826	0.743	0.74	0.7699	0.77	0.62	-0.6	-0.57	-0.54	0.33	0.34	0.3	0.2	-0	0.6931
LULC	0	0	0	0	0.055	0.042	0.085	0.08	0.0575	0.06	0.1	-0.1	-0.12	-0.07	0.05	0.06	0.1	0	0	0.0343
Max Temperature of Warmest Month	0	0	0	0	0	0.822	0.969	0.97	0.9899	0.99	0.88	-0.9	-0.76	-0.89	0.45	0.47	0.5	0.5	-0.1	0.7604
Mean Diurnal Range	0	0	0	0	0	0	0.675	0.67	0.7502	0.75	0.47	-0.6	-0.55	-0.73	0.05	0.08	0.1	-0	-0.1	0.9784
Mean Temperature of Coldest Quarter	0	0	0	0	0	0	0	1	0.993	0.99	0.97	-0.9	-0.79	-0.84	0.61	0.63	0.6	0.6	-0.1	0.584
Mean Temperature of Driest Quarter	0	0	0	0	0	0	0	0	0.9932	0.99	0.97	-0.9	-0.79	-0.85	0.61	0.63	0.6	0.6	-0.1	0.5847
Mean Temperature of Warmest Quarter	0	0	0	0	0	0	0	0	0	1	0.93	-0.9	-0.79	-0.87	0.55	0.57	0.6	0.5	-0.1	0.6719
Mean Temperature of Wettest Quarter	0	0	0	0	0	0	0	0	0	0	0.93	-0.9	-0.79	-0.87	0.55	0.57	0.6	0.5	-0.1	0.6716
Min Temperature of Coldest Month	0	0	0	0	0	0	0	0	0	0	0	-0.9	-0.74	-0.75	0.69	0.7	0.7	0.8	-0.1	0.3703
Precipitation of Coldest Quarter	0	0	0	0	0	0	0	0	0	0	0	0	0.865	0.962	-0.47	-0.48	-0	-1	0.1	-0.622
Precipitation of Driest Month	0	0	0	0	0	0	0	0	0	0	0	0	0	0.823	-0.57	-0.53	-1	-1	0.1	-0.493
Precipitation of Driest Quarter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.31	-0.32	-0	-0	0.1	-0.732
Precipitation of Warmest Quarter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.98	1	0.7	-0	-0.068
Precipitation of Wettest Month	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.7	-0	-0.027
Precipitation of Wettest Quarter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	-0	-0.032
Precipitation Seasonality	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.127
Slope	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.061
Temperature Annual Range	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5.6 Model sensitivity analysis:

The jackknife test gain (Figure 23, 24, 25) for *Yushania mailing, Chromolaena odorata, Hyptis suaveolens* respectively describes how important each variable is based on the 'gain' in the model with its inclusion. The jackknife test gain indentified elevation, max temperature of warmest month, min temperature of coldest month and isothermality as the most important environmental variables for predicting the potential habitat suitability of mailing bamboo in the study area. The jackknife test gain for *Chromolaena odorata* identified isothermality, Slope, precipitation of warmest quarter, Precipitation Seasonality and mean diurnal range as the most important environmental variables for predicting the potential habitat suitability of chromolaena odorata in the study area while the jackknife test gain of *Hyptis suaveolens* recognizes elevation, isothermality,mean diurnal range, slope and temperature seasonality as the most important environmental variables for predicting the potential habitat suitability of it. Interestingly no species identified land use as a determining factor for their habitat suitability.

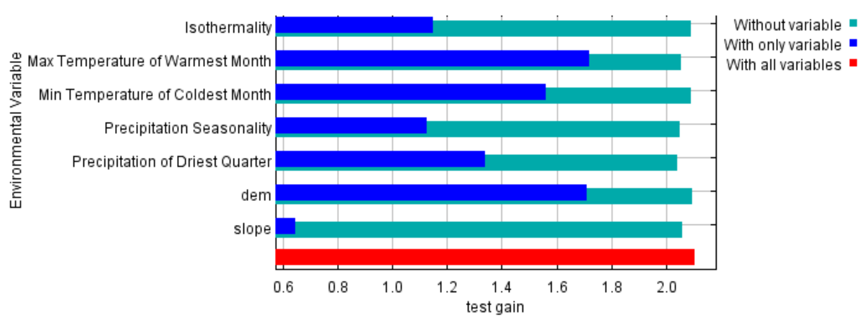

Figure 23 : Jackknife of test gain for *Yushania mailing* of individual environmental variable importance (blue bars) relative to all environmental variables (red bar

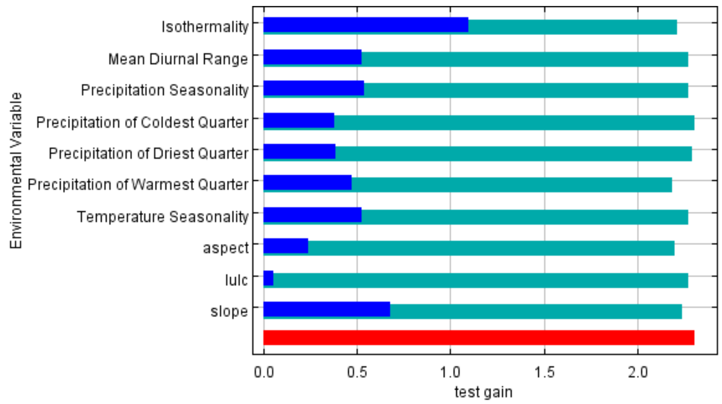

Figure 24 : Jackknife of test gain for *Chromolaena odorata* of individual environmental variable importance (blue bars) relative to all environmental variables (red bar)

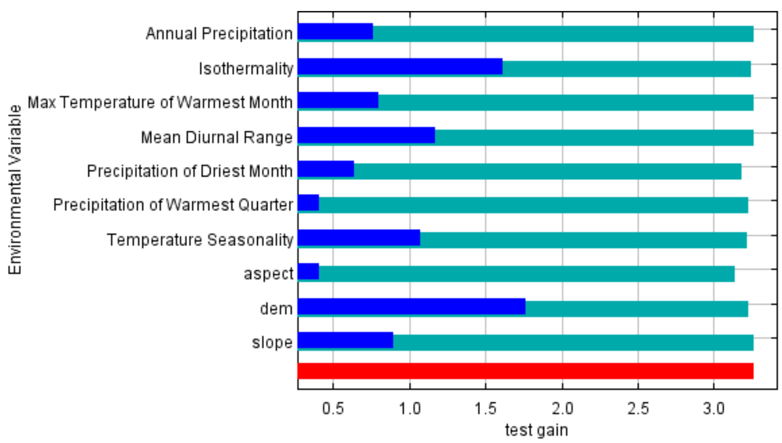

Figure 25 : Jackknife of test gain for *Hyptis suaveolens* of individual environmental variable importance (blue bars) relative to all environmental variables (red bar)

5.7 Risk Zonation

Figure 26, 27 and 28 shows the prioritized risk zone for *Yushania mailing, Chromolaena odorata, Hyptis suaveolens* respectively. It highlights the areas which could be very close to realized niche of species.

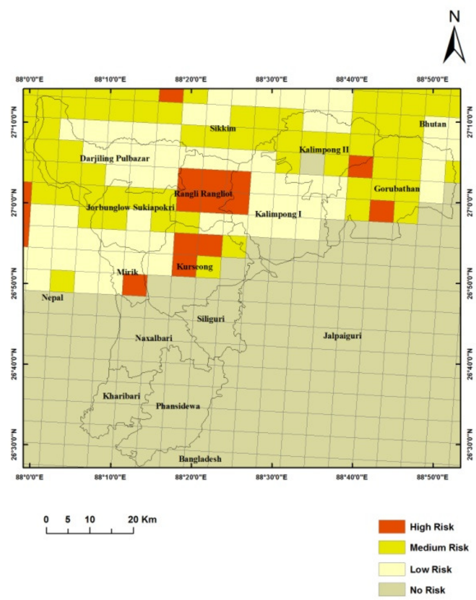

Figure 26: Invasion risk zonation of *Yushania mailing*

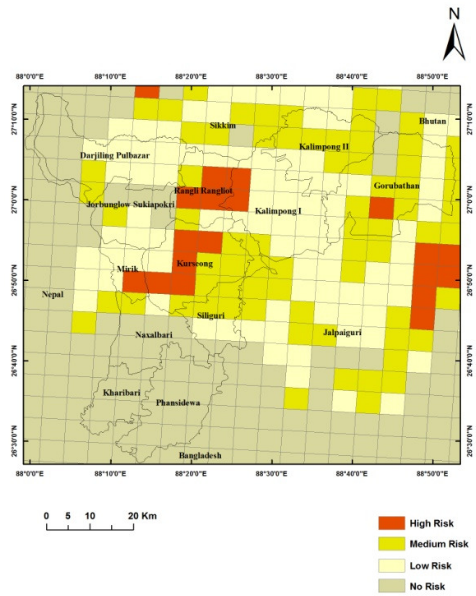

Figure 27 : Invasion risk zonation of *Chromolaena odorata*

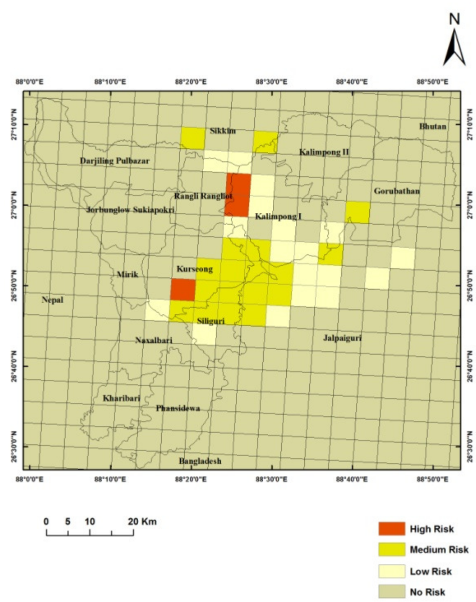

Figure 28 : Invasion risk zonation of *Hyptis suaveolens*

5.8 Discussion

Invasive species are a current focus of interest of ecologists, biological conservationists and natural resources managers due to their rapid spread, threat to biodiversity and damage to ecosystems. The global extent and rapid increase in invasive species is posing great threat to native biodiversity. Bio-invasion may be considered as a significant component on global change and one of the major causes of species extinction

In this study attempt was made to predict habitat suitability of three invasive species i.e. *Yushania mailing, Chromolaena odorata and Hyptis suaveolens* in Darjeeling Himalayas, which is a part of biodiversity hotspot and serves as a habitat for vivid kinds of rare and endangered species. In recent decades in Darjeeling Himalaya, several invasive plant species has invaded different natural and man-made ecosystems. There are concerns about the present and future spread of invasive and their impacts on local biodiversity. In this study species distribution modeling tools have been applied to address issues related to invasion. Species distribution modeling is particularly useful in modelling recently arrived, harmful invasive species because species may not yet have spread to all suitable habitats.

Study alarms about the present potential invasive species distribution and future threat possess by them on this naturally endowed region. Protected areas like Singallila National Park, Neora valley National Park, Senchal Wildlife Sanctuary and Barsay Wildlife Sanctuary are under high risk of invasion by mailing bamboo while Mahananda Wildlife sanctuary faces threat due to invasion by syam weed and bushmint. Habitat suitability of mailing bamboo lies at range of 1600 – 3600 meters i.e. upper temperate regions of Darjeeling Himalaya, which endangers variety of local and endemic flora of the region. Habitat suitability of syam weed was modelled at an elevation range of 160 – 1000 meters. Areas of mirik, Kurseong, Siliguri, Kalimpong and Rangli- rangliot are under high risk due to this invasive species. Agriculture lands, broadleaved mixed and moist deciduous forests are facing threat as they were predicted highly suitable habitat for syam weed in the study area. Low lying riverine areas were modelled as highly suitable for bushmint which resultantly possess threat to flora of riverine areas like various shrubs and grasses of medicinal and economic importance.

The selected invasive species were of varied habitats. Further attempt was to check for the reliability of selected species distribution models by assessing their prediction in diverse habitats. The study predicted precisely the potential habitat suitability distribution of selected invasive species for present as well as future climate change scenarios using habitat suitability models i.e. Maxent, GARP, BIOCLIM and ensemble modelling approach. The selected modelling approaches were highly significant in precisely predicting the habitat suitability of selected invasive species; Prediction was well in accordance with the locations where these invasive species presence was known. Additionally, this study discovered regions of potentially high risk for species invasion which were earlier unknown.

With the availability of fine resolution environmental variables and advancements in species distribution models based on presence and absence data, ecologists have been able to define extensive environmental conditions and niches suitable or unsuitable for species over large geographic regions. The modelling of potential distribution of invasive species in current and future climatic scenarios has provided a broader perceptive in invasion behavior studies. Recent advances in model fitting methods provide some assistance in more reliably selecting models. Even with a well-behaved algorithm, with few species records the model is likely to provide only a general indication rather than a realistic and detailed prediction. As a guideline, only attempt to model species with more than 20, and preferably 30 occurrences. Below this, the model is unlikely to be useful for conservation prioritisation. In the absence of sufficient records, the best options are to use an proficient model without species data, or to provide ancillary information by modelling the taxon of interest either with other species in a similar functional group or guild in a multi-response model (Elith and Leathwick 2007), or as a broader component of biodiversity.

The model compared in this study differs in terms of assumptions, algorithms and parameterization and therefore, evaluation of their performance is not straightforward. ROC based AUC provided a measure for model's performance.

In case of all the three invasive species considered in this study, the models the predicted area vary therefore a more robust model i.e. ensemble model was introduced in the study which combined the prediction strengths of individual models while eliminating the weakness of individual models. In order to provide a precise and robust estimate in terms of predicted habitat suitability area, the different model outputs have been ensemble. The uncertainty in the potential distribution predicted by different models can be minimized through ensemble modeling. Ensemble outputs have provided a measure of agreement/disagreement between the Maxent , GARP and BIOCLIM modelling algorithms used. This study has successfully highlighted the significance of ensemble modelling; however a void still remains is selecting threshold, consensus algorithm and its validation which leaves scope for further research.

The impact of climate change on the potential habitat suitability of invasive species was modeled using habitat suitability models. This has proven a great tool for the resource managers as they can be easily alarmed about the suitable areas of invasion before the actual arrival of invasive species and subsequently preventive measures could be adopted. Our result proves that climate change does alter the invasive species niches and could have uneven effects on the potential niches of invasive species. It can lead to translation of low suitable areas into moderately suitable areas, and moderately suitable areas into high suitable areas or vice-versa, however its strength varies from species to species. The highly habitat suitability area of invasive species may enlarge/shrink in the climate change scenarios. Further research is needed at larger scale to study the effect of climate change on their potential suitable niches.

Species distribution models and maps are an essential tool in risk analysis of invasive species. However, new field data to validate and improve the models are also essential. Especially with a rapidly invading species, the associated risks change equally quickly. Species adaptation to new modifying climates and environments change and their adding ecological and economic costs of effects and loss of local biodiversity are equally important for consideration. Various factors other than climate change like evolutionary changes, dispersal barrier, anthropogenic activities, fire, etc. are also responsible and play an important role in future spread of invasive species. Further studies and researches are therefore required which can incorporate such variables into a model to yield more robust and precise predictions.

Suitability of habitats cannot be appropriately distinguished from bioclimatic layers alone, and that remotely sensed land cover data significantly improved exclusively climate driven predictions. In related studies, improved results from contributions of remotely sensed land cover data have been mixed. On a coarse scale, inclusion of land cover data improved explanatory power, while having no effect on the predictive power of the models. A smaller spatial extent and finer resolution data may produce superior results.

The present study successfully identifies the risk zones which were possessing threat of invasion from respective invasive species. It captured the local invasive extent and threat of selected plant species specific to the particular ecosystems. The implementation of proper local and regional risk zonation schemes for screening the potential invasiveness zones of invasive species will reduce the risk of invasive species and thereby minimize ecological and economic impacts. The multi criteria invasive species risk zonation method described in this paper is easily adopted. The assessment method can be further developed and enhanced with advanced quantitative methods, if more relevant biological information on the taxonomic group of concern is available.

In general, Mirik, Kurseong, Gorubathan, Rangli Rangliot Kalimpong, Jourbunglow and Sukiapokhri parts of Drajeeling district and adjoining areas of Nepal , Bhutan and Sikkim are under high invasion risk. Risk zonation maps of invasive species, produced in this study can be used by resource managers for rapid response and early mitigation of the species. This will enable policy makers and land managers to prepare appropriate control and eradication strategies, and to estimate the ecological consequence such as drastic decrease or loss of biodiversity.

6 Conclusion and Recommendations:

6.1 Conclusion:

Species distribution models are powerful approaches to model distribution of invasive species. In this study, three theoretically different species prediction modeling techniques i.e. Maxent, GARP AND BIOCLIM were used to generate reliable scenarios of potential distribution of three invasive plant species invading different parts of Darjeling district , Sikkim (India) and adjoining areas in Nepal and Bhutan extending from tropical to temperate zones. The outcome of this study indicates that the predicted current potential distribution of selected invasive species in Darjeeling is over a large area. It extends from temperate regions to low lying regions of the study area. Mailing bamboo was dominant in temperate regions of the study area, while syam weed's habitat suitability was modeled in both tropical and subtropical regions of the study area. Bushmint was modeled in low lying tropical regions. Protected areas were also facing threat due to invasion in the study area.

The strength of model predictions and predicted maps varied with species and their varying habitats; however the selected species distribution models performed satisfactory under diverse habitats of invasive species. The results suggested that Maxent has better prediction accuracy as compared to GARP and BIOCLIM. The Maxent modelled habitat suitability for different invasive species was in general consistent with those resulting from GARP and BIOCLIM. The AUC predicted by Maxent was significantly higher than that of GARP and BIOCLIM predictions. Though AUC values were significant for GARP and BIOCLIM but they had less area under curve compared to that of Maxent suggesting weak predictions. Maxent had more area under curve at high significance level suggesting strong predictions.

Modelled future predictions under HADCM3 A2a and B2a 2050 scenarios showed that climate change does alter the selected invasive species potential niches and carries uneven effects on the potential niches of invasive species. It leads to translation of low suitable areas into moderately suitable areas, and moderately suitable areas into high suitable areas or vice-versa; however its strength varies from species to species. The habitat suitability area of selected invasive species was either enlarged or shrinked in the climate change scenarios. Syam weed showed an abrupt increase in suitable area under B2a scenario as compared to present and A2a scenario. Mailing bamboo showed increased suitable area in A2a scenario as compared to present and B2a scenario, while bushmint showed more suitable area in present scenario as compared to future scenarios. Bushmint showed greater resistance towards climate change i.e. not much significant niche alteration was observed.

The risk zonation scheme conceptualized and applied here approximates invasion risk at realized niche level. It provides a closer look at invasion risk as it matches with the realized niches of the selected invasive species rather than that compared with those produced from Species distribution models. The risk zones created from species distribution models are useful at regional scale due availability of coarse resolution climatic layers used in the study while risk zonation considering landscape structure, species richness and disturbance refine invasion risk zones at local scale.

6.2 Recommendations:

The following recommendations are proposed from the present study:

- Current and future potential distribution map of invasive species, produced in this study should be the part of biodiversity conservation planning of West Bengal Biodiversity board, forest departments and resource managers.

- The modelled distribution depicts potential distribution of invasive species in ecological space therefore efforts should be made to validate the distribution on the ground also. This will enable policy makers and land managers to priorities control and eradication activities, and to estimate the ecological consequence such as drastic decrease or loss of biodiversity

- Species distribution models are dependent on sample size and their spatial distribution. Therefore further attempts should be made to collect more number and well-distributed occurrences samples.

- Forest departments and resource managers must be in a constant cycle of collecting new field information regarding occurrences of various invasive species. A well prepared invasive species occurrence database will help to track invasive species spread. Various strategies should be formulated for containment or gathering new invasive species occurrence information.

- The pockets of concentration of rare and endangered species should be identified so that the magnitude of risk associated with it can be effectively assessed through risk analysis.

- The risk zonation methodology used here is simple and practical. It can be further refined through quantitative data on species and habitats. Grid based risk zonation in terms of high, medium and low risk areas would facilitate prioritization of conservation measures.

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