IMPACT OF CLIMATE CHANGE ON THE TEMPORAL AND SPATIAL DISTRIBUTION OF THE SELECTED MIGRATORY BIRD SPECIES IN KERALA

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THESIS

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2018

DECLARATION

I, Induja, B. (2012 – 20 – 102) hereby declare that this thesis entitled **"Impact of climate change on the temporal and spatial distribution of the selected migratory bird species in Kerala"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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SYMBOLS AND ABBREVIATIONS

AKN	Avian Knowledge Network
AUC	Area under the curve
bio1	Annual mean temperature
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
bio2	Mean diurnal range
bio3	Isothermality
bio4	Temperature seasonality
bio5	Maximum temperature of warmest month
bio6	Minimum temperature of coldest month
bio7	Temperature annual range
bio8	Mean temperature of wettest quarter

bio9	Mean temperature of driest quarter
CIAT	The International Centre for Tropical Agriculture
GBIF	Global Biodiversity Information Facility
GCMs	General Circulation Model
GHCN	Global Historical Climatology Network
GIS	Geographic Information System
HadGEM2-AO	Hadley Global Environment Model 2-Atmosphere-Ocean
IMD	India Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
MaxEnt	Maximum Entropy Modelling
NRC	National Research Council
RCPs	Representative Concentration Pathways
ROC	Receiver Operating Characteristic Curve
SD	Standard Deviation
SDM	Species Distribution Modelling
SRTM	Shuttle Radar Topography Mission
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
WGS84	World Geodetic System 1984
WMO	World Meteorological Organization

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CHAPTER 1

INTRODUCTION

The United Nations Framework Convention on Climate Change (UNFCCC) defined the climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods in contrary to the definition given by the Intergovernmental Panel on Climate Change (IPCC) as "any change in climate over time whether due to natural variability or as a result of human activity. In short, Earth's climate has always been changing from time to time. According to Foucal *et al.* (2006), subtle variations in the earth's orbit or change in the atmosphere or surface or otherwise variations in the sun's energy has changed the climate.

Global warming and climate change are terms for the observed century scale rise in the average temperature of the earth's climate system and its related effects. The global average surface temperature rose from 0.6□C to 0.9□C between 1905 and 2005, and the rate of temperature increase has nearly doubled in the last 50 years. Over the period 1880-2012, the globally averaged combined land and ocean temperature data showed a warming of 0.85□C (Collins *et al*, 2013).

The climate change prior to industrial revolution can be explained by natural phenomena. The warming since the mid-20th century is very unlikely explained by human activities. As per NRC (2010), human activities can explain most of this warming and so presently the increase in global average temperature is due to the observed increase in anthropogenic greenhouse gas concentrations. Anthropogenic climate change has a significant role on physical and biological systems all over the globe. A few degree changes in temperature can attribute marked difference in global environment.

Land use and land cover changes along with processes such as deforestation, reforestation, desertification and urbanization contribute greatly to climate change.

The global warming and climate change are a threat in the form of weather extremes and according to IPCC, their frequency would likely increase in the ensuing decades. These climate change effects may be significant regionally but are smaller when averaged over the entire globe.

The multiple components of climate change are anticipated to affect all the levels of biodiversity, from organism to biome levels. At the most basic level of biodiversity, climate change is able to decrease genetic diversity of populations due to directional selection and rapid migration, which could in turn affect ecosystem functioning and resilience. A sudden change in the climate requires larger and faster scales of adaptation than in the past. A single loss of species will lead to cascading effects since each organism are connected by food webs and other biological interactions. A growing body of evidence suggests that climate change is affecting the phenology (seasonal timing) of animal and plant activity at low altitudes.

It is projected that climate change will affect the species distribution both directly and indirectly. Species are affected in a different manner, many are forced to migrate at different rates through fragmented landscapes whereas the long-lived species dominating the ecosystem will be slow to show the evidence of climate change. Approximately 20 to 30% of plant and animal species assessed so far are likely to be at increased risk of extinction if increase in global average temperature is drastic. Species that are not able to adapt may be able to relocate, but only if alternative suitable habitats exist and are accessible; otherwise, these species will become extinct in the wild.

One dimension in which climate change effects on natural systems has been studied is in understanding its implications for potential geographic distributions of species. The migration of animals is linked to climate factors such as temperature, moisture availability and amount of daylight. Some animal and bird species will change their locations in search of a better place where the environmental conditions are favourable for their growth and reproduction. These migrations can be considered as a biological indicator of climate change as these species are expected to track the shifting climate.

Birds are one of the best-studied groups due to the widespread occurrence, ease of movement and high response to environmental conditions. They have the capacity to be important bioindicators because they are both popular and have a totemic status throughout the world that is understood by the general public and policy-makers. The implications for birds of climate change, i.e. long-term shifts in average weather, have only recently begun to be addressed. Many migrating birds are very sensitive to environmental changes and are already being affected by climate change. Increasing temperatures, changing vegetation and extreme weather conditions lead to significant changes of the birds' essential habitats.

Recently the Kerala state has been witnessing the increase number in arrival of certain migratory birds usually inhabiting the drier tracts of warmer countries. The change in climate has led to the species distributional change, especially causing migration changes in the avian species. The response of birds to climate change will vary from species to species, depending on how strongly their metabolism reacts to new temperature levels. Precipitation, along with temperature, is also especially likely to influence the behaviour of migratory birds.

According to Jose (2016), the expanding distribution of the Indian Peafowl (*Pavo cristatus*) may be considered as a warning about the spreading of dryness in Kerala. Similarly the increased number of arrival of the dry land inhabiting birds to the state could be an indication that something, especially related to climate is changing. The responses of birds to environmental perturbations, including climate can be estimated by using species distribution models (SDMs). These models are used to study the current distribution and predict the changes in the distributions that would happen in the future by incorporating the climate model data.

The present study is focused on modelling the change in distribution of the selected migratory bird species in Kerala using appropriate model techniques. It is hypothesized in the study that the increased distribution of these birds could be an indication that the climate in Kerala is changing. Eventhough there is lack of scientific explanation, observational and traditional experiences by biologists and bird watchers had made it as a conclusion.

The primary objective of this study is to find out the reasons for the expansion of the distribution of the selected migratory bird species in Kerala viz. Bunting species (Black-headed Bunting), Bluethroat, Lapwing species (Gray-headed Lapwing), Stonechat species (Common Stonechat) and Wheatear species (Isabelline Wheatear) to find out the possible reasons for the change in their distribution pattern. Using modelling techniques an ecological niche model is developed based on the current climate data and to project the regional shifts in the distribution pattern of these birds based on the results of the model in the changing future climatic conditions under different scenarios.

Earlier for studying the distributional change of the Indian Peafowl in Kerala, the same methodology was followed and it can be used for further modelling of distribution of different species. The present study matters about the impact of climate change on the selected migratory bird species and also benefit by predicting their future distributional changes. In a similar way, change in distribution of other significant species can also be studied.

CHAPTER 2

REVIEW OF LITERATURE

2.1 CLIMATE CHANGE AND BIODIVERSITY

Climate change was examined as one of the most uncertain and predominant threat to biological diversity. During the recent decades due to climate change, evident alterations had occurred in the different biological phenomena of biodiversity including the geographical ranges and abundance following further variations in the timing of growth, reproduction and migration events. It is projected that climate change will affect the species distribution both directly and indirectly. Species are affected in a different manner; many are forced to migrate at different rates through fragmented landscapes whereas the long-lived species dominating the ecosystem will be slow to show the evidence of climate change (IPCC, 2007).

Approximately 20 to 30% of plant and animal species assessed so far are likely to be at increased risk of extinction if increase in global average temperature is drastic (Daszak *et al.*, 2000; Root *et al.* 2003; Schwartz *et al.* 2006). Many changes in species composition, organism abundance, productivity and phenological shifts are found to be some of the effects of soaring high temperatures (Cramer *et al.*, 2001; Grimm *et al.*, 2008; Root *et al.*, 2003). One dimension in which climate change effects on natural systems has been studied is in understanding its implications for potential geographic distributions of species (Martinez-Meyer, 2005).

For conservation purposes, the future potential distributions of species have been projected by several studies (Aspinall and Matthews, 1994; Dunbar, 1998; Iverson and Prasad, 2001; Erasmus *et al.*, 2002; Bakkenes *et al.*, 2002; Beaumont and Hughes, 2002; Midgley *et al.* 2002; Peterson *et al.*, 2002; Midgley *et al.*, 2003; Burns *et al.*, 2003; Williams *et al.*, 2003; Meynecke, 2004; Ortega-Huerta and

Peterson, 2004; Skov and Svenning, 2004; Thomas *et al.*, 2004; Martínez-Meyer, 2005).The environmental parameters had important correlation with the distribution of species with an unpredictable effect (Freedman, 1983; Graham, 2003; Whittingham *et al.*, 2006; Platts *et al.*, 2008; Murray and Conner, 2009).

To estimate the effect of climate change on species, climatic envelopes are used and the environment warms by shifting the geographic location of these envelopes and thus the species will migrate to suitable habitats while some others respond to the warmer temperatures (Sharma, 2011). For assessing the effects of environmental alterations and climate change on biodiversity and ecosystem processes phenology could be recognized as a robust ecological indicator (Bharali and Khan, 2011).

2.2 CLIMATE CHANGE IN KERALA

According to the India Meteorological Department (IMD) in Kerala during the last 43 years from 1961-2003 the maximum, minimum and mean temperature had increased respectively by 0.8°C, 0.2°C and 0.5°C. Rao *et al.* (2009) reported that there was an increase in the maximum and minimum temperature by 0.64°C and 0.23°C respectively with overall annual average temperature of 0.44°C during the period of 49 years (1956 to 2004) in Kerala.

Using the data up to1980 detailed study on the onset of monsoon and monsoon rainfall over Kerala was done (Ananthakrishnan and Soman, 1988a; 1989).Many studies supported the decreasing trend in the southwest monsoon rainfall over Kerala (Soman *et al.*, 1988b; Guhathakurta and Rajeevan, 2007). Kumar *et al.* (2008; 2009) studied the temporal variation in monthly, seasonal and annual rainfall over Kerala and analysed significant decrease in southwest monsoon rainfall during June and July while increase in post-monsoon rainfall during January, February and April over the state of Kerala (Gateway of summer monsoon).

In Kerala according to the India Meteorological Department (IMD) results published on 2013, there was remarkable increase in the annual mean, maximum and minimum temperature, annual mean diurnal temperature range, winter mean maximum temperature, summer mean maximum temperature, average summer mean diurnal temperature range, monsoon mean maximum temperature, monsoon mean temperature and post monsoon temperature but decline in the annual average rainfall, winter rainfall, summer mean rainfall and monsoon rainfall except the post monsoon rainfall (Rathore *et al.*, 2013).

As per Raj and Azeez (2009, 2010) the annual rainfall, winter rainfall and the southwest monsoon in the Palakkad Gap in the Western Ghats is significantly less in accordance with the entire state of Kerala owing to the variation with altitude.

Nayagam *et al.* (2008) utilized the variables of ocean and atmosphere and developed a linear multiple regression model to long range forecast monsoon rainfall of Kerala. The study using factor analysis regarding the variation in the rainfall occurrence showed a significant impact by the state's general physiography and added that the altitude and rainfall in Kerala are uncorrelated (Simon and Mohankumar, 2004).

Pal and Al-Tabbaa (2009) reported that Kerala would be vulnerable to increased water scarcity in the pre-monsoon time and a delaying monsoon onset due to the decline in spring seasonal extreme rainfall with increased frequency of the dry days whereas the winter and autumn extreme rainfall found to have an increasing tendency.

2.3 BIRD MIGRATION AND CLIMATE CHANGE

Birds are one of the best-studied groups due to the widespread occurrence, ease of movement and high response to environmental conditions. They track climate change and a large number of studies have detected climate impacts on vital rates and population abundance. They have a recognizable and iconic status throughout the world and hence considered as important bio-indicators (Crick, 2004).

Temperature played a significant role in the phenological events like migration and reproduction of birds due to climate change and responded accordingly across species, geographic regions, and trophic levels. Phenotypic plasticity helps many of the birds to cope up with the seasonal timing of life cycle changes thereby combating natural year-to-year spring temperature variations (Wormworth and Sekercioglu, 2011).

In climate science present global warming is indicated by the phenological shift in birds (Visser *et al*, 2006). According to Wormworth and Sekercioglu (2011), phenological responses caused by global warming produce wide range effects for the birds.

Dunn and Winkler (2010) reported that the bird's responses to climate change would help to understand the processes driving the alterations in phenology. Townsend *et al*. (2013) reported that in New Hampshire the inter-annual variations in temperature from 1986-2010 were clearly tracked by the black-throated blue warblers.

With no variations in migration strategy but due to the change in breeding and wintering areas some of the numerous long-distance migrants will suffer from climate change preventing adequate adaptation (Both and Visser, 2001). Mistiming in the migratory pied flycatcher as a result of climate change is probably a widespread phenomenon and it evidently can lead to population declines (Both *et al*., 2006).

2.4 TROPICAL WARMING AND HABITAT ISLANDS OF BIRDS

From the modelling results it is suggested that with 2^0C of warming the area having favourable climate of bower birds in the Wet Tropics bioregion in Australia declined by 90 percent with 10 percent decrease in rainfall and a more than 3^0C warming in future leads to the complete disappearance of the bird's favourable climate (Hilbert *et al.*, 2004). Most endemic bird areas occupying 77 percent of the avian diversity regions are seen in the tropics and subtropics (Stattersfield *et al.*, 2005; Sekercioglu, 2011).

According to Sekercioglu (2011) the ability to respond to climate change is less for birds with slower lives. Modelling results imply that when considering tropical bird population adaptation to temperature variability, the chance of tropical regions to be affected by climate change is even more or similar to that of temperate regions (Bonebrake and Mastrandrea, 2010).

The warming trend in Madagascar due to climate change had reached around the global average threatening the existing bird populations. Due to warming the birds of Madagascar now confined to habitat fragments were forced southwards and at the same time those attempting to shift to higher elevations may be prevented by habitat fragmentation (Raxworthy *et al.*, 2008).

Climate envelope modelling suggests that more than half of the area of suitable climate for the endemic bower bird, mountain thornbill, Acanthizakatherina, Atherton scrubwen, Sericorniskeri, within their core environments would be lost with an average warming of 1^0C (Wormworth and Sekercioglu, 2011).

According to Shoo *et al.*, (2005) accounting bird's abundance and expected range shifts, model suggests that up to 41 species (74 percent) of Wet Tropics' rainforest birds are threatened due to mid-range (1.4-3.6^0C) regional warming. As per Wormworth and Sekercioglu (2011) since 1500 the majority (88 percent) of the 153 bird extinctions have taken place on islands even though more than 80 percent of bird species are found on continents.

The temperature lapse rate about 6.5^{0}C leads to a greater rate of temperature decrease for a given dispersal distance achievable through pole ward shifts (Wormworth and Sekercioglu, 2011) and according to Colwell *et al*., (2008) tropical bird species disperse along elevational than latitudinal gradients in response to warming. The mountain bird species are on an escalator to extinction as a result of climate warming (Sekercioglu, 2007).

2.5 CLIMATE CHANGE, ABUNDANCE AND EXTINCTION OF BIRDS

Climate change and global warming can be considered as major drivers of changes to bird abundance and community composition and also as an extinction threat. Other than phenology and distribution, bird abundance and community composition changes form the important fingerprints of climate change. One assessment revealed that at least 24 critically endangered bird species are threatened by climate change and associated severe weather. Roughly one in eight bird species are threatened with global extinction from human impacts, superimposed by climate change risks (Wormworth and Sekercioglu, 2011).

The sooty shearwater species, regardless of its buffering strategy and status as one of the world's most abundant, was listed as 'near threatened' by the IUCN in 2004. But there was a decline by around 90 percent in the sooty shearwater population that spend North American summers in the California Current due to increase in sea surface temperatures (Viet *et al*., 1997). The results obtained by combining climate envelope modelling with observed population trends for common and widespread European birds is an indication that after the mid-1980s, a period of rapid warming, there was a detectable influence of climate change on bird populations(Gregory *et al*., 2009).

According to Wormworth and Sekercioglu (2011) the dependence of migratory birds on multiple habitats points the effect of global warming on their populations via diverse mechanisms. McKechnie and Wolf (2010) reported that it is harder for small desert birds to sustain their water balance in hotter weather due to climate change and by 2080 will lead to more frequent cases of catastrophic mortality. In Europe, there was a sharp population decline among the 110 common species with the lowest thermal maxima during 1980-2005 (Jiguet *et al.*, 2010).

Climate change also affects bird's survival indirectly, mainly via its effects on their food supplies. Climate change-induced mismatch in the common cuckoo led the Royal Society for the Protection of birds to red list it in 2009 owing to a 59 percent decline since the 1960s in the UK (Wormworth and Sekercioglu, 2011).

By 2100, according to the Snake Summit in the UK's South Pennies modelling suggests a reduction in prey abundance due to unabated warming causing a local golden plover population to become extinct. In 2008, Birdlife International found extreme events to be the top climate change threat to critically endangered species (Wormworth and Sekercioglu, 2011).

According to van Vliet and Leemans (2006) extreme events can be expected to have devastating effects on ecosystems and species in future, even if climate change is moderate. The California arid-land bird's populations die even at a modest increase in the frequency of arid conditions (Bolger *et al.*, 2005).

One of the IPCC's finding that climate change will lead to the global increase in drought-affected areas is an obstacle to bird's survival as it drives large shift in the bird abundance thereby makeup of their communities (Albright *et al.*, 2009). Global warming cause the increased frequency of most intense cyclones as suggested by many models with powerful effects on birds (Knutsun *et al.*, 2010).

According to Wormworth and Sekercioglu (2011) a research on an Isle of May population of European shags doubt on their capacity to ride out more extreme weather in the future. From modelling results, Schmutz (2009) reported that the European shag's population gets extinct probably if one more winter with survival rate less than that during 1994 occurs per 40year period. The impact of the greater environmental variables and extremes expected with highly variable survival rates is far from trivial (McLachlan *et al.*, 2007).

The trend in rising density of collared flycatchers with temperatures in the Czech Republic signalled a march towards competitive exclusion of pied flycatchers during warm periods (Saetre *et al.*, 1999).The IUCN finds the hazard for two-thirds of the climate change susceptible birds as their inability to disperse to suitable habitats, a greater global warming threat (Wormworth and Sekercioglu, 2011).

Migratory species, compared to sedentary ones are less or near threatened to extinction (Sekercioglu, 2007). As per Sekercioglu *et al.* (2008) the chance that sedentary birds go extinct by 2100 due to climate change and habitat loss is 5 times more than long-distance migrants. The vulnerable migratory bird species are highly threatened the ongoing climatic changes leading to the risk of extinction (Moller *et al.*, 2008).

Around nine percent of adults of Crozet Archipelago perished with a sea surface warming of 0.26°C at

Possession Islands in a period of nine years and the current global warming predictions argued that the King Penguins over there are at high extinction risk. On the other hand the potential to evolve quickly and better adapt to climate change are owned by birds with shorter generation times and in some cases climate warming could even improve the survival of young birds, especially in the Arctic region (Wormworth and Sekercioglu, 2011).

A 36 percent chance of collapse in Terre Adelie emperor penguin colony due to increasingly frequent warming events expected a potential decline from 6000 breeding pairs to mere 400 pairs by 2100 (Jenouvrier *et al.*, 2009). About 35 percent of living bird species assessed among 9856 numbers is deemed to be susceptible to climate change by IUCN (Foden *et al.*, 2009).

Sekercioglu *et al.* (2008) found that by 2100, 400 to 500 of the world's 8459 land- bird species will go extinct due to 2.8°C surface warming. The population of bird species with small ranges occurring in rare climates will shrink with climate change leaving it highly vulnerable as suggested by climate models (Ohlemuller *et al.*, 2008).

According to Shoo *et al.* (2005) nine out of 12 endemic species in the Wet Tropics of Queensland, than the range contractions total population size drop faster by warming. By 2070 the habitat of globally threatened spoon-billed sandpiper could be reduced by more than half by a warming of just 1.7°C (Zockler and Lysenko, 2000).

2.6 SPECIES DISTRIBUTION MODELLING

Species distribution models were used to study the spatial configuration and characteristics of habitats that allowed the existence of species in landscapes (Araujo and Williams, 2000; Ferrier *et al.*, 2002; Scotts and Drielsma; 2003). The past distributions, future distributions and relationships between environmental factors and species richness also could be studied (Jose, 2016). For species distribution modelling, known information regarding the species distribution is acquired along with the definition of environmental conditions and identify the geographical regions having similar environment (Pearson and Dawson, 2003).

In species distribution modelling the prediction of the species distribution is done using the presence or absence data in relation to a particular environment predictor in various fields of ecology, evolution and conservation (Elith *et al.*, 2006). Using climatic envelope models the reliability of future distribution of species under changing climatic conditions were analysed. (Akcakaya *et al.*, 2006; Pearson *et al.*, 2006; Araujo and Rahbek, 2006; Zimmer, 2007). The current bird species distribution and prediction of the future bird distribution using the present climate data and future climate data could be done by modelling (Huntley *et al.*, 2006). Predictive models had been developed using the association between Emphasizing more on birds, predictive models had been developed in connection with climate and vertebrate distribution (Jetz *et al.*, 2007).

2.7 MAXIMUM ENTROPY MODELLING (MAXENT)

MaxEnt is a type of species distribution model (SDM) which predicts the habitat of a given species using the presence only data. Since presence only datasets are widely available and concern over climate change grows, MaxEnt is getting more popular (Phillips and Dudik 2007). To determine the density of a species within its habitat, or to predict the suitability of area for a species outside its present habitat, MaxEnt is helpful.

While creating a model, Maxent randomly generates background points based on the ecological interests, may be the current habitat extent or a wider range to compare with the observed presence data (Merow *et al.,* 2013). Other than the presence data Maxent models also require importing raster layers that describe the environmental conditions intended to measure against the study species.

MaxEnt is well-suited for species distribution modeling as it is a method for general intend, involved in making predictions or results from incomplete data with a simple and precise mathematical formulation (Phillips *et al*., 2006). The various influences of climatic factors in establishing the bioclimatic ranges were studied using MaxEnt (Elith *et al*., 2011; Yang *et al*., 2013; Halvorsen, 2013). MaxEnt can build the model accurately even though there is lack of dependable locations for mapping the spreading of species as it deals with less number of occurrence points (Baldwin, 2008).

2.8 FACTS ABOUT THE SELECTED MIGRATORY BIRDS

The Black-headed Bunting (*Emberiza melanocephala*) belongs to the bunting group constituting long distance migrants representing the Palaearctic-Indian migratory system. Their breeding grounds are in East Europe, Asia, Palestine, Syria, Upper Mesopotamia and Persia while wintering grounds are throughout western and central India primarily in Rajasthan, Uttar Pradesh, Madhya Pradesh, Gujarat, Maharashtra and Karnataka (Srivastava, 2014). The distribution modelling suggests that the potential range of the Black-headed Bunting in northern Italy is restricted to a small area due to both climatic and habitat features (Brambilla, 2014).

The Bluethroat (*Luscinia svecica*) is a polytypic species breeding in the northern Palearctic from Scandinavia to Alaska and from the Siberian arctic tundra to the Himalayan Mountains and wintering in Iberia, the southern Mediterranean region, in Africa, the Middle East and India. In Israel, the wintering areas of the Bluethroat are low-lying areas in damp habitat near water in the northern valleys, in the desert near sewage plant and in oases (Markovets and Yosef, 2005). Hagelin (2015) examined the variations in the breeding distribution of the Bluethroat, with regard to latitude and altitude in Norway for the last 35 years (1980-2014) in order to identify the effect of climate change on them.

The Gray-headed Lapwing (*Vanellus cinereus)* is a wetland bird distributed from East Asia to Southeast Asia especially in lowland farms and riverbeds with wintering grounds in southern China, Indochina, Myanmar, Bangladesh, India, Nepal and parts of mainland Southeast Asia, which is suspected to be a rare winter visitor to peninsular India (Kumar *et al*, 2003). They are regular winter visitors to Bihar, southern Assam hills, south-western Bengal and Odisha, a few spotted at Delhi and Bharatpur (Rajasthan), Kashmir, northern and southern Gujarat and later reported from Maharashtra, Andhra Pradesh, Goa, Karnataka, Tamilnadu and beyond 1999 from Kerala (Roshanth, 2017). The expansion of wintering range of the Gray-headed Lapwing towards the equator in Sumatra could be correlated with climate change (Patil *et al*, 2012).

The Stonechat (*Saxicola torquata*) is a common breeding resident in Europe, Asia and Africa, seen in the waterless areas of Trans-Caspian and Trans-Aral deserts with the wintering range from southern Japan south to Thailand and India and west to north-east Africa. The habitat types are marsh areas, moors, deciduous forests and open pasture lands. According to Sparks *et al.* (2002), global warming is likely to benefit resident species like the Stonechat which suffer badly during harsh winters in Britain. Due to climate change the phenological variation in birds had an effect on age of migration in stonechats (Tomotani *et al*, 2016).

Greater-spotted Eagle (*Clanga clanga*) breeds in Europe, Russia and NE China. The wintering grounds are Southern Europe, Africa, Pakistan, India (mainly to about West Maharashtra), Southern and Eastern China, and Indochina (Meyburg *et* al, 2016). It is a common winter visitor to most of northern India, but rare in the peninsula inhabiting a wide variety of lowland open habitats, particularly wetlands (Santhakumar *et al*., 2016). In India this species winters widely, especially in the northern parts and there are a few records from Tamil Nadu, Karnataka, Andhra Pradesh and Goa. As per the birdwatchers the Greater-spotted Eagle was spotted in Kattampally (Kannur), Punchakkari (Thiruvananthapuram) and Kole wetlands of Thrissur.

Isabelline Wheatear (*Oenanthe isabellina*) breeds in Afghanistan and Pakistan and its wintering ground is Pakistan and north-western India, suspected to be a rare winter migrant to Sri Lanka and in the Maldives. . It is found in the open country, barren tracts of land, arid and semi-arid regions, steppes, sandy grounds and the borders of cultivated lands. They were spotted at the eastern slopes of the Western Ghats, drier areas of the Konkan, Goa, and the Deccan Plateau in Andhra Pradesh, Raichur district in Karnataka, Kannur and Kottayam districts in Kerala (Muthunarayanan *et al*., 2013).

CHAPTER 3
MATERIALS AND METHODS

3.1 DATA FOR THE STUDY

The datasets used for the current study are mainly categorized in to two:

- Bird occurrence data
- Climate data

3.1.1 Bird Occurrence Data

The occurrence locations of the selected migratory bird species viz. Lapwing species, Wheatear species, Aquila species, Bunting species, Stonechat species, Bluethroat were collected from the e-Bird database (www.eBird.org). The e-Bird is an online checklist program freely available, which provides data on bird abundance and distribution at a variety of spatial and temporal scales. It is launched in 2002 by the Cornell Lab of Ornithology and National Audubon Society. The e-Bird data are part of the Avian Knowledge Network (AKN) which in turn feeds data to international biodiversity data systems, such as the Global Biodiversity Information Facility (GBIF). The Breeding Bird Survey data from 1966 is available at e-Bird. The geo-referenced data of the selected migratory birds till 2016 (year round) for India were downloaded from the e-Bird database. From that the bird data for Kerala state were filtered out and the unwanted bird locations were cleared using Microsoft excels tools.

3.1.2 Climate Data

The climate data for the present and future time periods, used extensively in this research were obtained from WorldClim v1.4 database (http://www.worldclim.org/download) (Hijmans *et al.*, 2005). This WorldClim data is a set of global climate layers (climate grids) with a spatial resolution of 30 arcs second of about 1 square kilometer, very useful for mapping and spatial modeling in

GIS. By inferring a species' environmental requirements from localities where it is currently known to occur, WorldClim data is useful in predicting the distribution of species under current, past and future climatic conditions (Hijmans and Graham, 2006).

For the entire globe, the WorldClim climate data of past, present and future is available in the form of monthly precipitation, maximum temperature and minimum temperature. From this data 19 bioclimatic variables are derived that are mainly used in this study. These variables are derived from the monthly rainfall and temperature values in order to generate more biologically meaningful variables, represent annual trends, seasonality and extreme or limiting environmental factors.

The 19 bioclimatic layers are described as follows:

3.1.2.1 Bio1 (Annual Mean Temperature): It is the average temperature for each month averaged over twelve months. The total energy inputs for an ecosystem are approximated using the annual mean temperature.

3.1.2.2 Bio2 (Annual Mean Diurnal Range): It is the mean of the monthly temperature ranges (monthly maximum minus monthly minimum). To capture diurnal temperature range recorded temperature fluctuation within a month is used. Each monthly diurnal range (difference between the month's maximum and minimum temperature) is then averaged over the twelve months of the year. The relevance of temperature fluctuation for different species is understood.

3.1.2.3 Bio3 (Isothermality): It quantifies how large the day to night temperatures oscillate relative to the summer to winter (annual) oscillations. The ratio of the mean diurnal range (Bio 2) to the annual temperature range (Bio 7, discussed below) and then multiplying by 100. This predictor is useful in ascertaining the influence by larger or smaller temperature fluctuations within a month relative to the year on species distribution.

3.1.2.4 Bio4 (Temperature Seasonality (Standard Deviation): The amount of temperature variation over a given year (or averaged years) based on the standard deviation (variation) of monthly temperature averages. It is a measure of temperature change over the course of the year. The variability of temperature is greater with larger standard deviation.

3.1.2.5 Bio5 (Max Temperature of Warmest Month): The maximum monthly temperature occurrence over a given year (time-series) or averaged span of years (normal). The effect of warm temperature anomalies species distributions throughout the year is examined.

3.1.2.6 Bio6 (Min Temperature of Coldest Month): The minimum monthly temperature occurrence over a given year (time-series) or averaged span of years (normal). Whether species distributions are affected by cold temperature anomalies throughout the year is examined.

3.1.2.7 Bio7 (Annual Temperature Range): A measure of temperature variation over a given period calculated by subtracting Bio 6 from Bio 5. The effect caused by ranges of extreme temperature conditions on species distributions is interpreted.

3.1.2.8 Bio8 (Mean Temperature of Wettest Quarter): It is the approximation of mean temperatures that prevail during the wettest season. Examination of the effect of environmental factors on species seasonal distributions can be done using the provided mean temperatures during the wettest three months of the year.

3.1.2.9 Bio9 (Mean Temperature of Driest Quarter): Approximation of mean temperatures prevailing during the driest quarter. Mean temperatures during the driest three months of the year is provided which can be useful for examining how such environmental factors may affect species seasonal distributions.

3.1.2.10 Bio10 (Mean Temperature of Warmest Quarter): It is the approximation of mean temperatures that prevail during the warmest quarter. Mean temperatures during the warmest three months of the year is helpful in studying the effect of environmental factors on species seasonal distributions.

3.1.2.11 Bio11 (Mean Temperature of Coldest Quarter): Mean temperatures that prevail during the coldest quarter are approximated. For examining the effect of environmental factors on species seasonal distributions, mean temperatures during the coldest three months of the year are provided.

3.1.2.12 Bio12 (Annual Precipitation): It is the sum of all total monthly precipitation values. Annual total precipitation approximates the total water inputs and is therefore useful when ascertaining the importance of water availability to a species distribution.

3.1.2.13 Bio13 (Precipitation of Wettest Month): It is the total precipitation that prevails during the wettest month. Whether a species potential range is influenced by extreme precipitation conditions during the year is identified.

3.1.2.14 Bio14 (Precipitation of Driest Month): Total precipitation that prevails during the driest month. The effect of extreme precipitation conditions during the year on a species potential range is inferred.

3.1.2.15 Bio15 (Precipitation Seasonality): A percentage of precipitation variability of which variation in monthly precipitation is added over the course of the year. The ratio of the standard deviation of the monthly total precipitation to the mean monthly total precipitation. Greater variability of precipitation is understood from larger percentages.

3.1.2.16 Bio16 (Precipitation of Wettest Quarter): It is the approximation of total precipitation that prevails during the wettest quarter. To determine the effects of environmental factors on species seasonal distributions total precipitation during the wettest three months of the year.

3.1.2.17 Bio17 (Precipitation of Driest Quarter): The total precipitation that prevails during the driest quarter is approximated. Total precipitation during the warmest three months of the years infers the effect of environmental factors on species seasonal distributions.

3.1.2.18 Bio18 (Precipitation of Warmest Quarter): Approximation of the total precipitation that prevails during the warmest quarter. Total precipitation during the coldest three months of the year is provided for examining environmental effects on species seasonal distributions.

3.1.2.19 Bio19 (Precipitation of Coldest Quarter): It is the approximation of total precipitation prevailing during the coldest quarter, the coldest three months of the year, for studying the environmental factors affecting species seasonal distributions.

The temperature data are in the unit °C *10 and that of precipitation in mm. Average monthly climate data from weather stations on a 30 arc-second resolution grid (1 km^2 resolution) are interpolated to generate the bioclimatic layers. These layers cover the global land areas, are located in the latitude or longitude coordinate reference system and the datum is WGS84. The bioclimatic variables were calculated by aggregating the data for monthly precipitation, minimum, mean and maximum temperature. There are both advantages and disadvantages for this data.

The WorldClim interpolated climate layers were made by using the major climate databases compiled by the Global Historical Climatology Network (GHCN), the Food and Agriculture Organization of the United Nations (FAO), World Meteorological Organization (WMO), the International Center for Tropical Agriculture (CIAT), R-HYdronet and a number of additional minor databases for Australia, New Zealand, the Nordic European Countries, Ecuador, Peru, Bolivia, the SRTM database and the ANUSPLIN software which interpolates noisy multi-variate data using thin plate smoothing splines.

The current bioclimatic layers correspond to the time period from 1950 to 2000, were used for modelling the present distribution status of the selected migratory birds. To carry out the modelling process for the future prediction of distribution of these bird species, the same current bioclimatic layers and future bioclimatic layers were used. Both data are available in the WorldClim database. The future bioclimatic layers include the climatic responses of all the four scenarios of Representative Concentration Pathways (RCPs) such as RCP2.6, RCP 4.5, RCP 6.0 and RCP 8.5 for the years 2050 and 2070 generated using the coupled model HadGEM2-AO of 30 seconds resolution.

Table 1. Different RCP's and its characteristics

Name	Model used	Radiative forcing	CO2 equivalent (ppm)	Temperature anomaly (°C)
RCP2.6	IMAGE	3.1 W/m^2 at mid-century, returning to 2.6 W/m^2 by 2100	490	1.5
RCP4.5	MiniCAM	4.5 W/m^2 post 2100	650	2.4
RCP6	AIM	6 W/m^2 post 2100	850	3.0
RCP8.5	MESSAGE	8.5 W/m^2 in 2100	1370	4.9

3.2 MODEL USED IN THE STUDY

For the selected migratory bird species, the species distribution was studied using MaxEnt 3.3.3k. This software is based upon the maximum-entropy principle, freely available online (https://www.cs.princeton.edu/~schapire/MaxEnt/). This species habitat modelling software uses a set of geo-referenced occurrence locations and environmental layers obtained from WorldClim database to create the species distribution model. Here the selected migratory bird species data was made into '.csv' format and the bioclimatic layers in to '.asc' format. Software was programmed to appropriate levels according to our requirements for the run under settings options (Philips *et al.*, 2004; 2006).

3.3 REPLICATION RUN TYPES USED IN MODELLING

In the present study, cross-validation and subsampling forms of replication were used.

In the case of cross-validation the occurrence data were randomly split into numerous k folds of equal size and the model is run k times with each fold being withheld once for testing. The number of folds would dictate the number of replicates and the size of the test data set. Each fold constitutes usually 20% or so of the dataset. The model was trained using all presences except one of the groups, then test the model against these groups using some performance measures. Model performance is averaged across groups and presumably better reflects a model's ability to predict to new data. Cross-validation would be helpful in dealing with small number of data sets. It assessed the uncertainties in prediction, reported the range and standard error during model evaluation. It was difficult to retrieve test data which was statistically independent of training data since cross-validation used only a part of the data for model fitting (Hijmans, 2012; Wenger and Olden, 2012).

Subsampling is the better form of replication run done under MaxEnt modelling. Generally preferred for running the models with moderate to many number of occurrence points. In repeated subsampling the presence data sets were repeatedly split into random training and testing subsets. Here it is able to fix the number of replications and test percentages before executing the run. As per De Bin *et al.*, (2015), subsampling utilised weak effect variables with low inclusion frequencies due to the correlation between other variables.

3.4 VARIABLE CONTRIBUTION TO THE MODEL

Analysis had done to identify the contribution of each variable to the modelling of distribution for the selected migratory bird species, including all bioclimatic variables. This was done for current distribution (no future projection), by using cross- validation where 25 percent of the data for testing and the remaining data were used to build the model. In the study cross-validation was done for the migratory birds viz. the Black-headed Bunting and the Isabelline Wheatear at different replication numbers of 25, 30, 35 and 40. The remaining birds such as the Bluethroat, the Gray-headed Lapwing, the Stonechat and the Greater-spotted Eagle were modelled by using the subsampling form of replication with test percentages of 10, 15, 25 for 30, 35 replications. The output was made in logistic format to get the probability of occurrence in the range of 0-1. In the determination of the percentage contribution, the increased regularized gain is added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda is negative in each repetition of the training algorithm. For the estimation of permutation importance, the values of each environmental variable on training presence and background data were randomly permuted.

3.5 ACCURACY OF THE MODEL

The accuracy of the model is determined by running the model using different test percentages of 10, 15, 25 and replication numbers of 30 and 35. Omission curves and AUC curves obtained as output in the model determine the accuracy of the model. (Philips *et al.,* 2006; Elith *et al*., 2011). The analysis of omission/commission graph explained that the orange and blue shading shows the variability. In accordance with the convention of cumulative output the predicted omission rate was a straight line. So regarding the better models, omission rate should be close to the predicted omission. The area under the Receiver Operating Characteristic (ROC) curve or area under the curve (AUC) is exhibited by the sensitivity vs. 1-specificity graph and found efficient in distinguishing the performance of one model with the other. An AUC value close to 1.0 indicated better model performance while a value of 0.5 indicated that the model performance was not much satisfactory. Using these features of MaxEnt output, the various models projected under different test percentages and replication numbers were analysed and the best fitted model based on the ROC curve and having high AUC value was selected (Philips *et al*., 2006).

3.6 FUTURE PREDICTIONS OF DISTRIBUTION FOR THE SELECTED MIGRATORY BIRD SPECIES

In MaxEnt model, the trained environment layers are projected to another set of environment layers containing the future climatic data set in order to predict the species distribution of the selected migratory bird species in the future. The projection layers should have trained layers which were mutually compatible but the conditions will be different. The name of the layers and the map projection should be the same as that of the trained data. A model was trained on the environmental variables which corresponded to the current climatic conditions and was projected into a separate layer based on the future environmental data. Models of different RCPs were done using 25, 30, 35 and 40 numbers of replications and test percentage of 10, 15, and 25. The projection was also done using cross-validation and subsampling forms of replication.

CHAPTER 4

RESULTS

4.1 DISTRIBUTION DETAILS OF THE SELECTED MIGRATORY BIRDSPECIES IN THE PAST AND PRESENT

Starting from the time of British ornithologists and followed by eminent experts such as Salim Ali, Kerala's Bird population has been well documented. According to IMD statistics in the 1950-2016 periods, the temperature of the state has gone up by 0.66^0C. During the period 1935-1936, Salim Ali and Hugh Whistler conducted a bird survey of Kerala and reported no evidence of Indian peafowl, usually found in the drier tracts of central and northern India. Later on 1969, Ali spotted Indian peafowl on the deciduous forests of Peechi-Vazhani and the trend has increased during the subsequent periods.

Similarly a group of wildlife biologists and bird watchers across the Kerala state have been tracking and identifying atleast 36 species of dry-land birds in Kerala for the past 15 years which were not historically reported yet. Some of the identified birds include Bunting species (Black-headed Bunting), Wheatear species (Isabelline Wheatear), Aquila species (Greater-spotted Eagle), Lapwing species (Gray-headed Lapwing), Stonechat species (Common Stonechat) and Bluethroat. At first the sightings were sporadic and then they became more regular, indicating the increased presence of these birds in Kerala.

4.2 REPLICATION RUN TYPES USED IN MODELLING

The current study for modelling the species distribution of migratory birds was carried out using cross-validation and subsampling forms of replication under the MaxEnt model. In cross-validation all the data is used for validation. For the study cross-validation is applied for modelling the bird species with small number of datasets (occurrence points). Here the data is efficiently used for reporting the range and standard error and every feature was exactly the same as other models. The species with moderate to many occurrence points were modelled by running the subsampling form of replication. The number of replicates and the percentage to be withheld from each replicated run is fixed in this replication type. Replication run types using cross-validate and subsampling showed different AUC values, omission/commission graphs, distribution patterns of species, response curves and variable contributions.

In the study cross-validation was done for the migratory birds viz. the Black-headed Bunting and the Isabelline Wheatear at different replication numbers of 25, 30, 35 and 40. The remaining birds such as the Bluethroat, the Gray-headed Lapwing, the Stonechat and the Greater-spotted Eagle were modelled by using the subsampling form of replication with test percentages of 10, 15, 25 for 30, 35 replications. Correspondingly the predictions of future distribution of these bird species were done using cross-validation and subsampling using the four different RCP values.

4.3 BLACK-HEADED BUNTING

To select the better model for accurate results, 4 different models were run by MaxEnt and the corresponding AUC values and SD was analysed for the given bird. The sampling type was cross-validation with different number of replicates and test percentages (mentioned above).

Table2. Average test AUC values and SD of each model of the distribution of the Black-headed Bunting

Model trial no:	AUC values	SD
1	0.810	0.200
2	0.815	0.202
3	0.806	0.197
4	0.808	0.203

Here the first model was selected as the better one for the modelling of species distribution at the present time. First and second models have the highest AUC values and comparing the second one SD is lower for the first model.

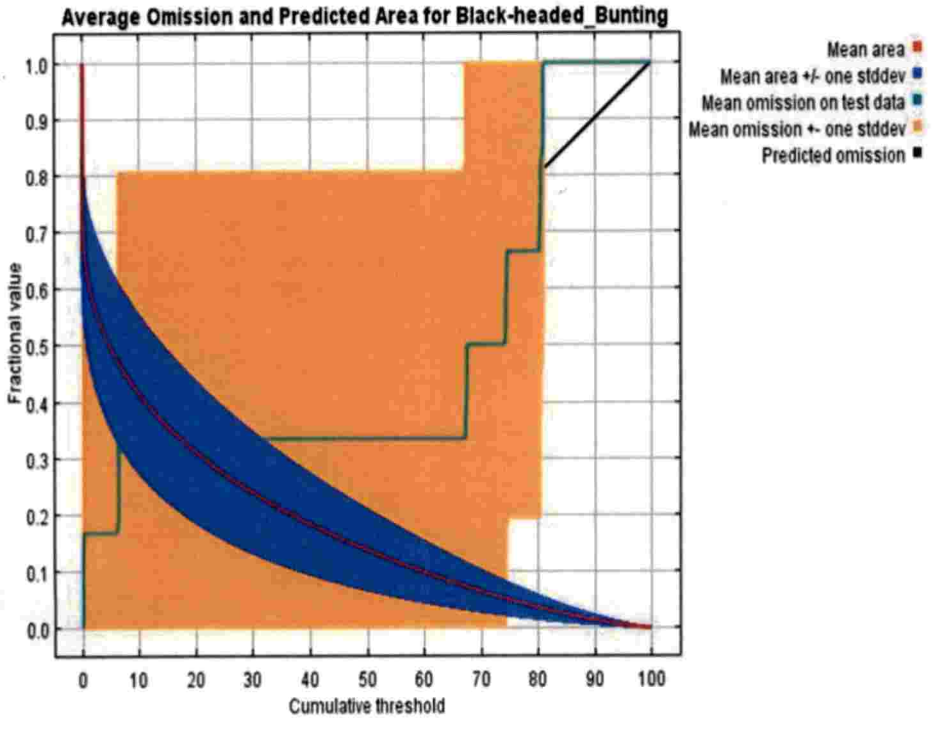

Figure1.shows the Test omission rate and predicted area as a function of the cumulative threshold, averaged over the replicate runs for Black-headed Bunting

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Here the test omission rate could not fit comfortable with the model. There was variation in the path of the mean omission line as it was not passing close to the predicted omission line.

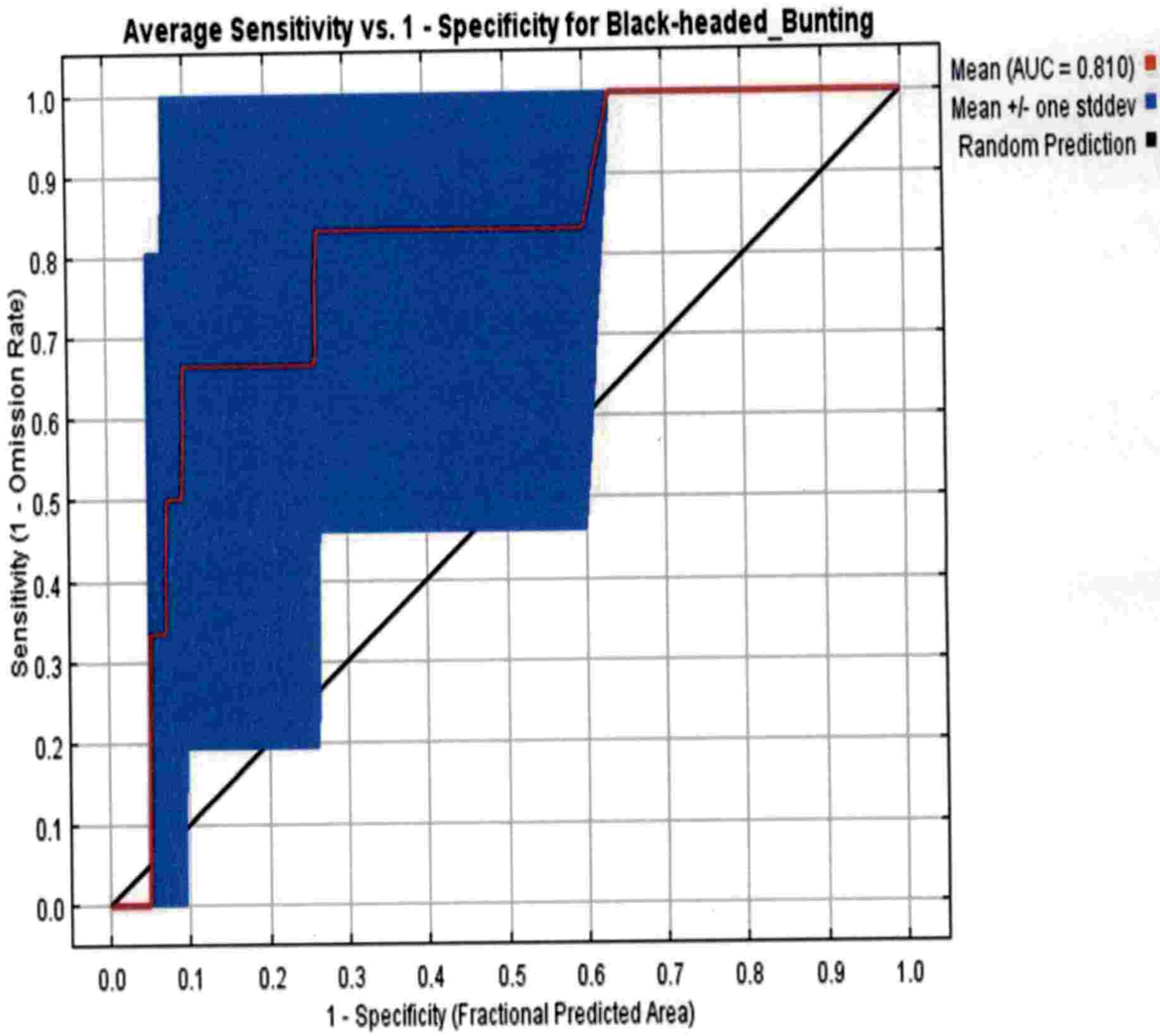
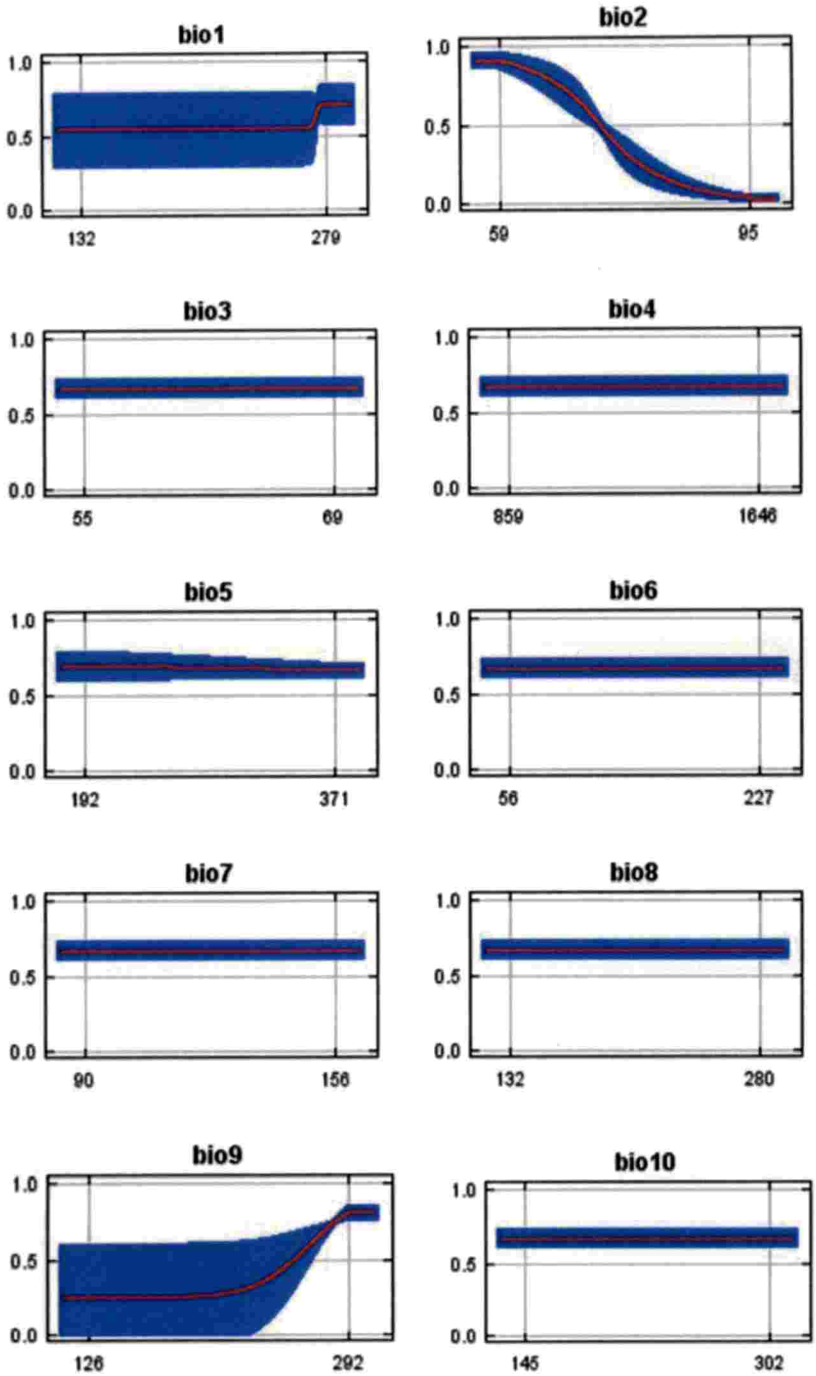


Fig2. Depicts the ROC curve averaged over the replicate runs of the given model for the Black-headed Bunting

Here the ROC curve is not leading a continuous path but passes through the left top of the random prediction.


bio1
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bio4
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1646
bio5
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371
bio6
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0.5
0.0
56
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bio7
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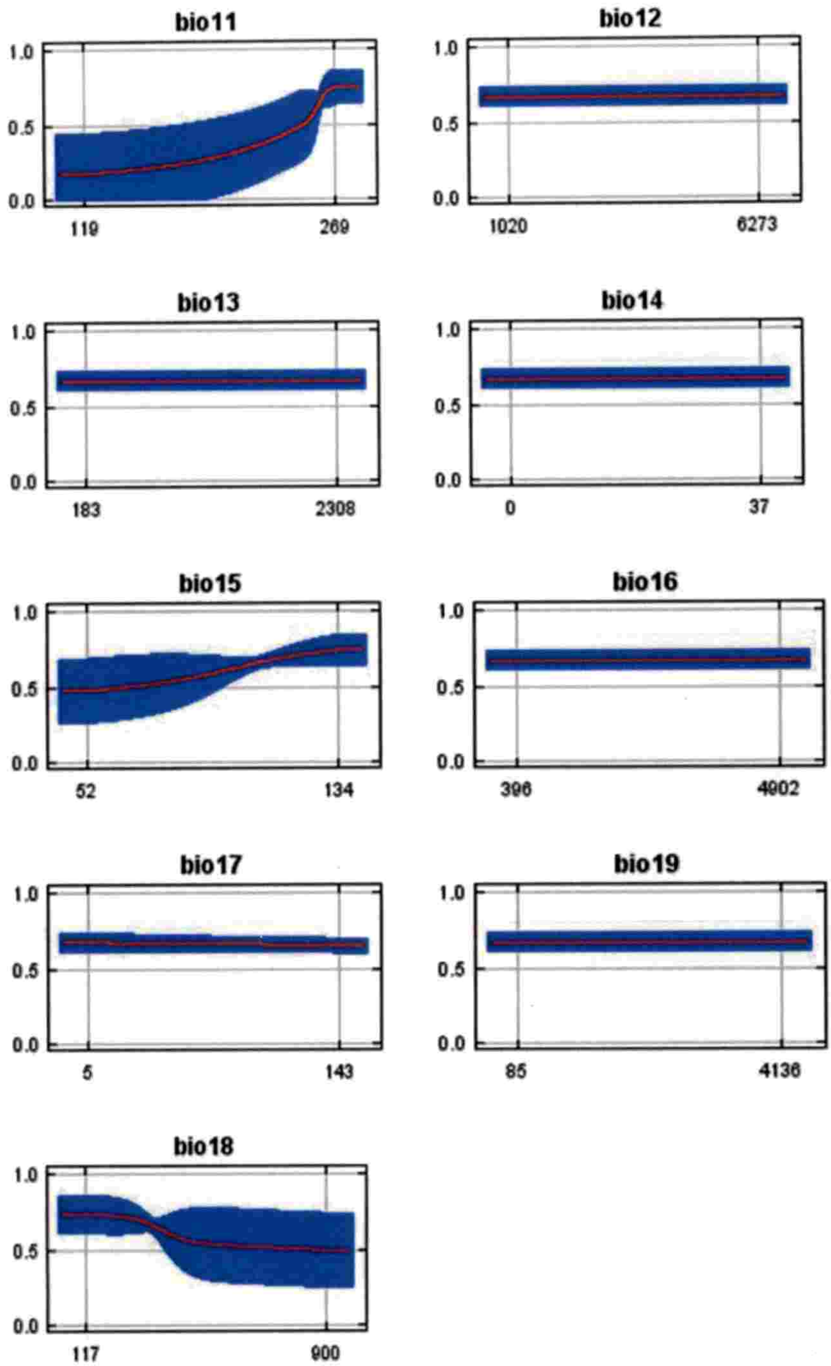
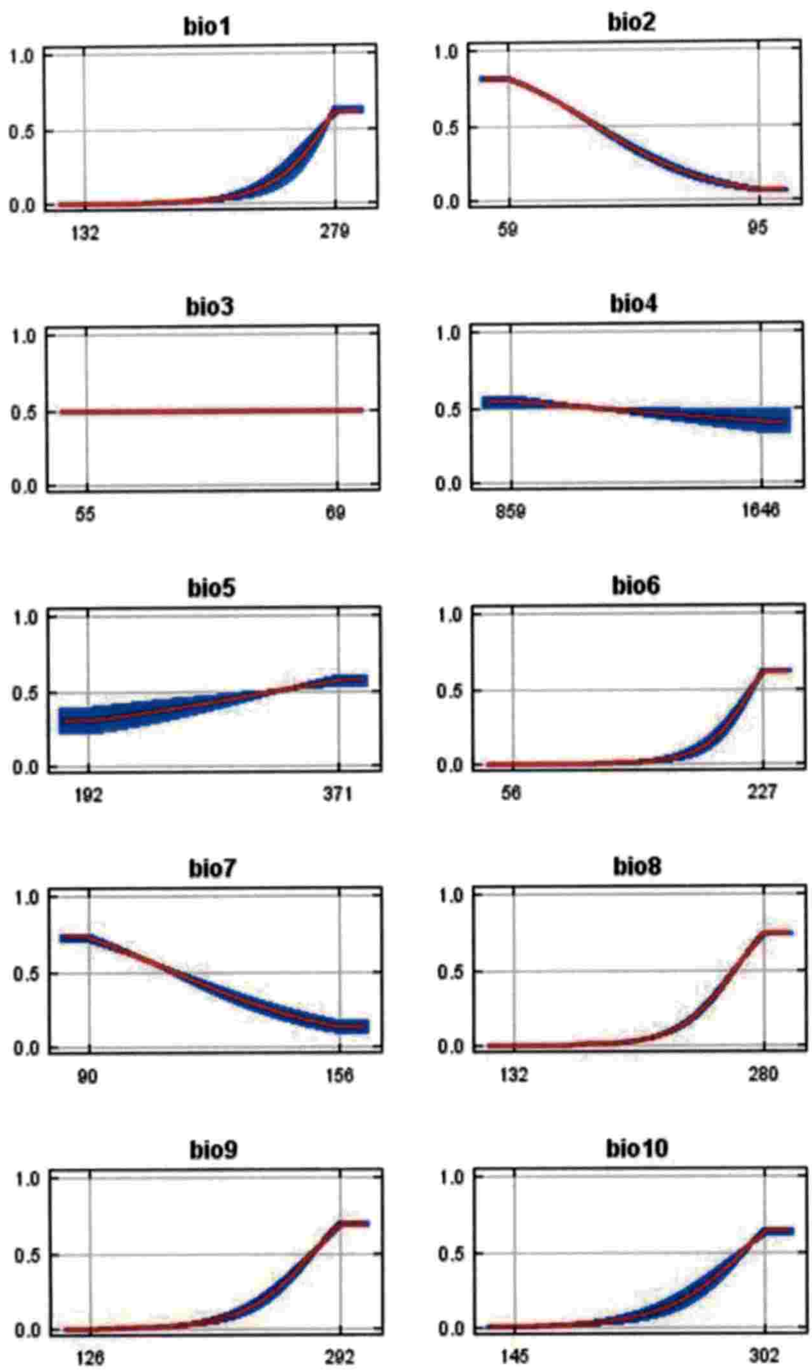


Fig3. Response curves of each variable in the distribution of the Black-headed Bunting keeping all other variables at their average values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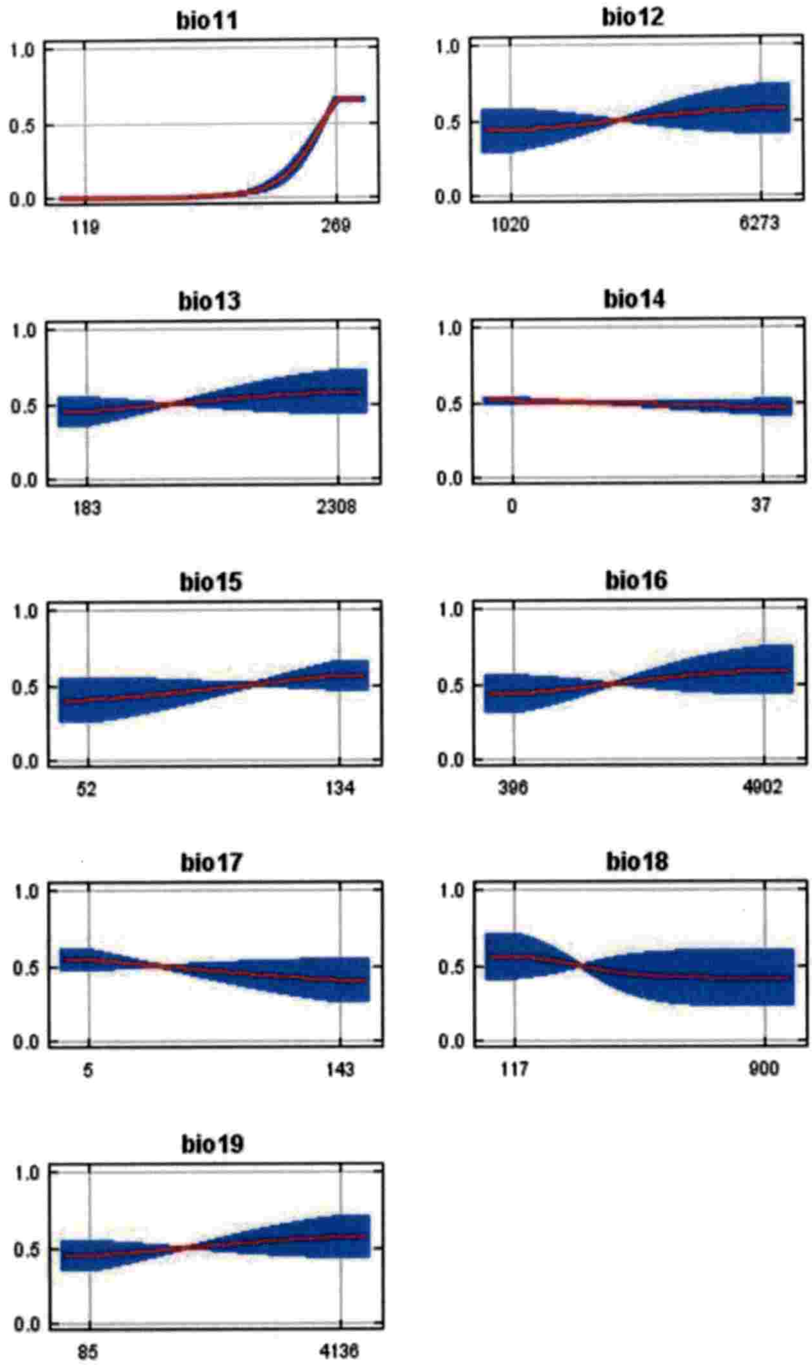

Fig4. Response curves of each variable in determining the distribution of the Black-headed Bunting created using only the corresponding variable

4.3.1 VARIABLE CONTRIBUTION TO THE MODEL DISTRIBUTION OF THE BLACK HEADED BUNTING

Table3. Percent contribution and permutation importance of all environmental variables to the model for Black-headed Bunting

Variable	Percent contribution	Permutation importance
Bio2	38.2	38.6
Bio6	26.8	0
Bio1	7.5	7.2
Bio11	6.9	5.1
Bio9	6.4	35.8
Bio18	5.4	7.2
Bio15	5.3	6.1
Bio17	3.4	0
Bio5	0	0.1
Bio4	0	0
Bio3	0	0
Bio19	0	0
Bio16	0	0
Bio14	0	0
Bio13	0	0
Bio12	0	0
Bio7	0	0
Bio10	0	0
Bio8	0	0

The percent contribution and permutation importance of all the environmental variables are given by the MaxEnt output and it is shown in Table.3. Among the variables the mean diurnal temperature (bio2) showed higher percent contribution

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and about eight variables such as bio5, bio4, bio3, bio19, bio16, bio14, bio13, bio12, bio7, bio10, and bio8 didn't showed any contribution at all. Other than the minimum temperature of the coldest month (bio6), six variables showed contribution less than 10. Mean diurnal range of temperature (bio2) and mean temperature of warmest quarter (bio9) shows more importance with 38.6 and 35.8 percent respectively in the case of permutation. The variables likebio11, bio1, bio18, bio15 and bio5 showed importance less than 10.

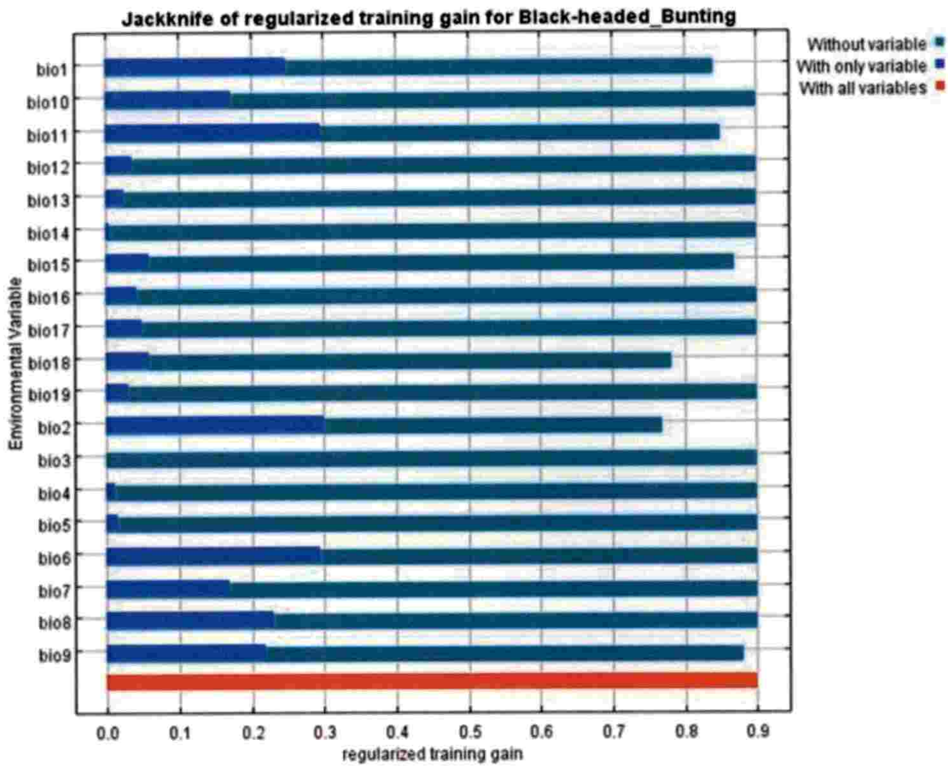


Fig. 5. Jackknife analysis of regularized training gain for the Black-headed Bunting using all the variables

The results of the jackknife test of variable importance shown in Fig.5. tell that the environmental variable with highest gain when used in isolation is bio2, which therefore appears to have the most useful information by itself. The variables bio6 and bio11 lies very next to bio2 while considering the gain. The environmental variable that decreases the gain the most when it is omitted is bio2, which therefore appears to havethemost information that isn't present in the other variables. Also bio 18 shows a lesser gain, lower than 0.8.

The response curves from the MaxEnt output (Fig.3)are the curves with logistic prediction changes as each environmental variable has varied, keeping all other environmental variables at their average sample value. Positive responses were shown higher by bio1, bio9, bio11 and bio18 compared to the moderate responses by bio3, bio4, bio5, bio6, bio7, bio8, bio10, bio12, bio13, bio14, bio16, bio17 and bio19. Some variables like bio18, bio2 shown less significance to the survival of species.

The response curves from the MaxEnt output (Fig. 4) showed the change in predicted probability when the corresponding variable is only used. Positive responses were shown by bio1, bio5, bio6, bio8, bio9, bio10 and bio11 compared to the moderate responses by bio3, bio12, bio13, bio15, bio16, and bio 19. Negative responses were shown by bio2, bio4, bio7, bio14, bio17, and bio18.

4.3.2 Current and future predictions of the distribution of the Black-headed Bunting

Using the MaxEnt model and 19 environmental variables, the current distribution pattern of the Black-headed Bunting in Kerala was found. The presence records of the Black-headed Bunting were used for modelling purpose. The distribution pattern for the given bird in Kerala is depicted in Fig.6. Mainly in the low lands of Thiruvananthapuram, Kannur and Kasargode districts the bird distribution found abundant with a probability of 0.69. Also some sort of abundance was seen in the lowlands of Thrissur, Kollam, Malappuram and Kozhikode districts having a probability greater than 50 percent.

The future distribution of the Black-headed Bunting in Kerala for the years 2050 and 2070 was predicted by projecting the 19 environment variables under four different Representative Concentration Pathways (RCP) such as RCP2.6, RCP4.5, RCP6.0, and RCP8.5.

The predicted distribution of the Black-headed Bunting in 2050 under the RCP2.6 model is given in Fig. 7. It was observed that the distribution of the Black-headed Bunting would expand to the low lands and mid lands of Thiruvananthapuram, lowlands of Thrissur, low lands and midlands of Malappuram, then to the districts of Kozhikode, Kannur and Kasargode at a probability of 0.89. There would also be a probability of expansion of bird distribution to mid lands and high lands of Thrissur and regions of Palakkad.

The predicted distribution of the Black-headed Bunting in 2050 under the RCP 4.5 model is given in Fig. 8. It was observed that the distribution of the Black-headed Bunting would expand to the districts of Thiruvananthapuram, Alappuzha, Kozhikode, Kannur, Kasargode and the low and mid lands of Kollam. Also the spread would be expected to the low and midlands of Malappuram and Thrissur districts. The mid lands of Palakkad and high lands of Thrissur will probably witness the expansion of the Black-headed Bunting distribution.

The predicted distribution of the Black-headed Bunting in 2050 under the RCP 6.0 model is given in Fig. 9.A strong southward expansion of the Black-headed Bunting was seen under the RCP6.0 model predictions to the low lands, mid lands and high lands of Thiruvananthapuram and Kollam, low lands of Alappuzha, midlands of Pathanamthitta and Kottayam with a probability of 0.95. Also the spread of distribution would be expected to the lowlands of Kasargode, lowlands and midlands of Kannur and Kozhikode, lowlands of Malappuram and Thrissur. There would be spread of bird distribution to the mid lands of Palakkad and high lands of Thrissur.

The predicted distribution of the Black-headed Bunting in 2050 under the RCP 8.5 model is given in Fig. 10. According to RCP 8.5 model, the abundance of distribution of the Black-headed Bunting would be higher towards the northern and southern regions of Kerala, mainly towards the low lands and mid lands of Kannur, Kasargode and Kozhikode, low lands and middle lands of Thiruvananthapuram, low lands and middle lands of Kollam, low lands and middle lands of Pathanamthitta, low lands of Alappuzha. Based on this model prediction, the probability of The Black-headed Bunting would become more in the mid lands of Kottayam, low lands of Ernakulam, low lands and mid lands of Thrissur, low lands of Malappuram.

The predicted distribution of the Black-headed Bunting in 2070 under the RCP 2.6 model is given in Fig. 11. The model shows that the northward and southward tips of Kerala would be rich in abundance of distribution of the Black-headed Bunting. Certain parts of Kozhikode, low lands and mid lands of Malappuram, some parts of low lands of Thrissur and the low lands of Kollam would be probable to distribution of Black-headed Bunting.

The predicted distribution of the Black-headed Bunting in 2070 under the RCP 4.5 model is given in Fig. 12. According to the model, the abundance of distribution of the Black-headed Bunting would be greater in the low and mid lands of Thiruvananthapuram and Kasargode and low lands of Kannur. There would be spread of distribution to low lands and mid lands of Kozhikode, low lands of Alappuzha, mid lands of Kottayam and mid lands of Pathanamthitta.

The predicted distribution of the Black-headed Bunting in 2070 under the RCP 6.0 model is given in Fig. 13. The distribution of Black-headed Bunting would be strongly expanding to the low lands mid lands and high lands of Thiruvananthapuram, low lands and mid lands of Kollam, low lands of Alappuzha, mid lands of Pathanamthitta, low lands and mid lands of Kozhikode, Kannur and Kasargode. There would be spread of distribution to the low lands of Kottayam, low and mid lands of Palakkad, Ernakulam, Thrissur and Malappuram.

The predicted distribution of the Black-headed Bunting in 2070 under the RCP 8.5 model is given in Fig. 14. According to the model, the abundance of distribution of Black-headed Bunting would be richer in the low lands, mid lands and high lands of Thiruvananthapuram, low lands, mid lands, and high lands of Kollam, low lands and mid lands of Pathanamthitta, mid lands and high lands of Alappuzha, low lands, mid lands and high lands of Kasargode, Kannur, Kozhikode. There would be more spread of distribution in the low lands, mid lands and high lands of

Malappuram, low and mid lands of Palakkad, low and mid lands of Thrissur, low and mid lands of Ernakulam. There would be distribution of the Black-headed Bunting in the high lands of Palakkad at a probability of 0.77.

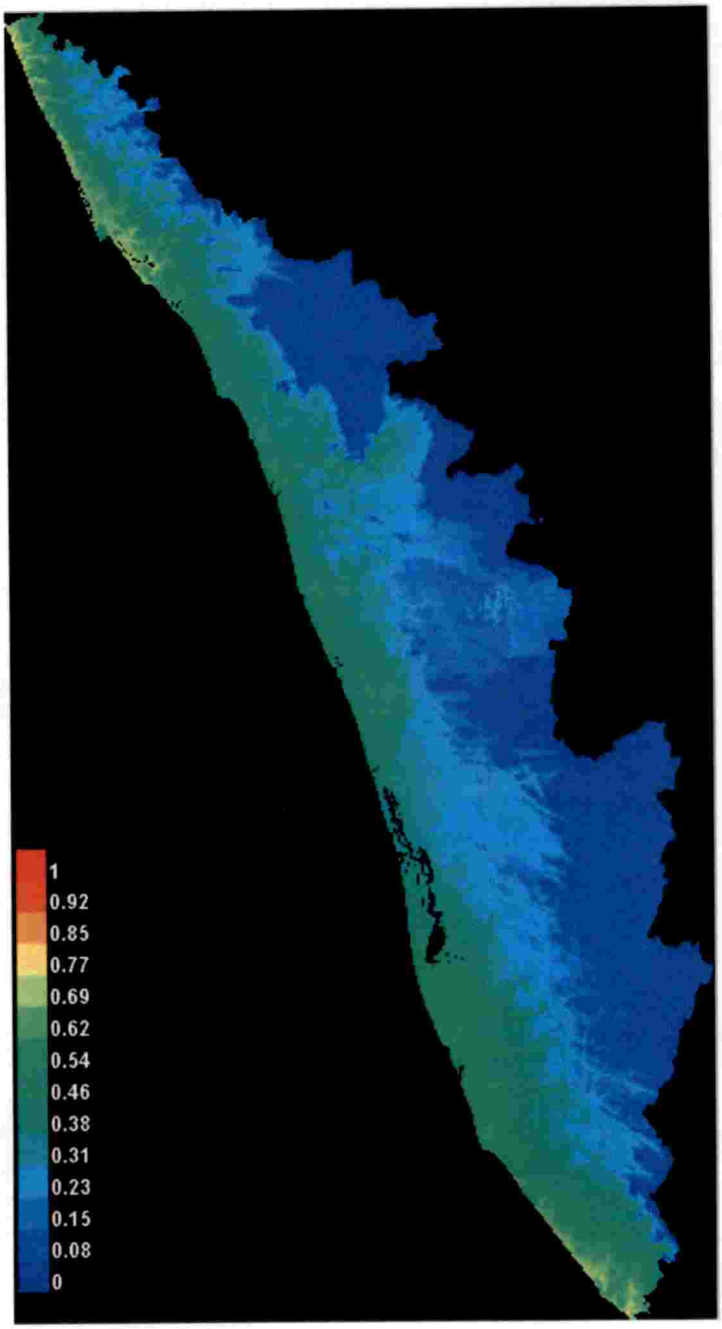


Fig.6. Current distribution of the Black-headed Bunting in Kerala

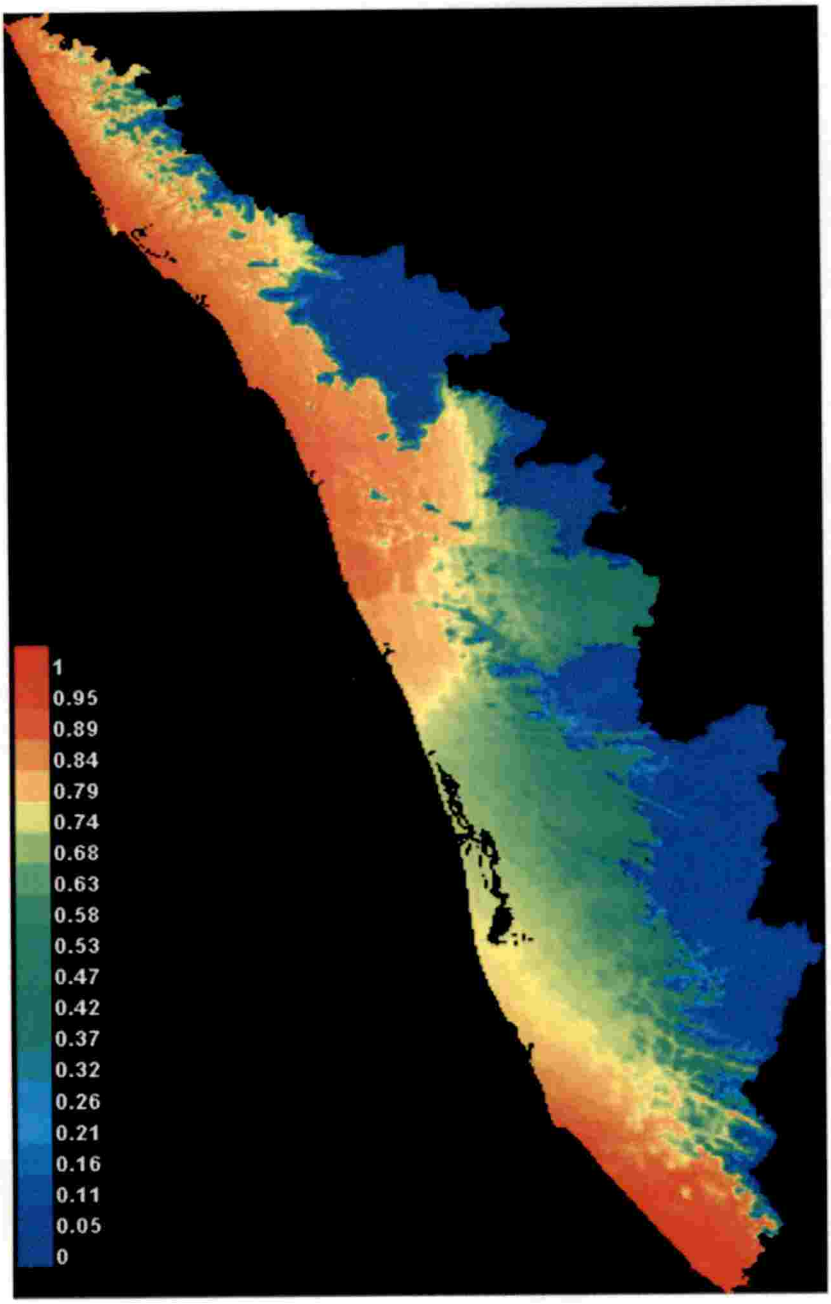


Fig. 7. Prediction of the future distribution of the Black-headed Bunting for 2050 under RCP 2.6 prediction

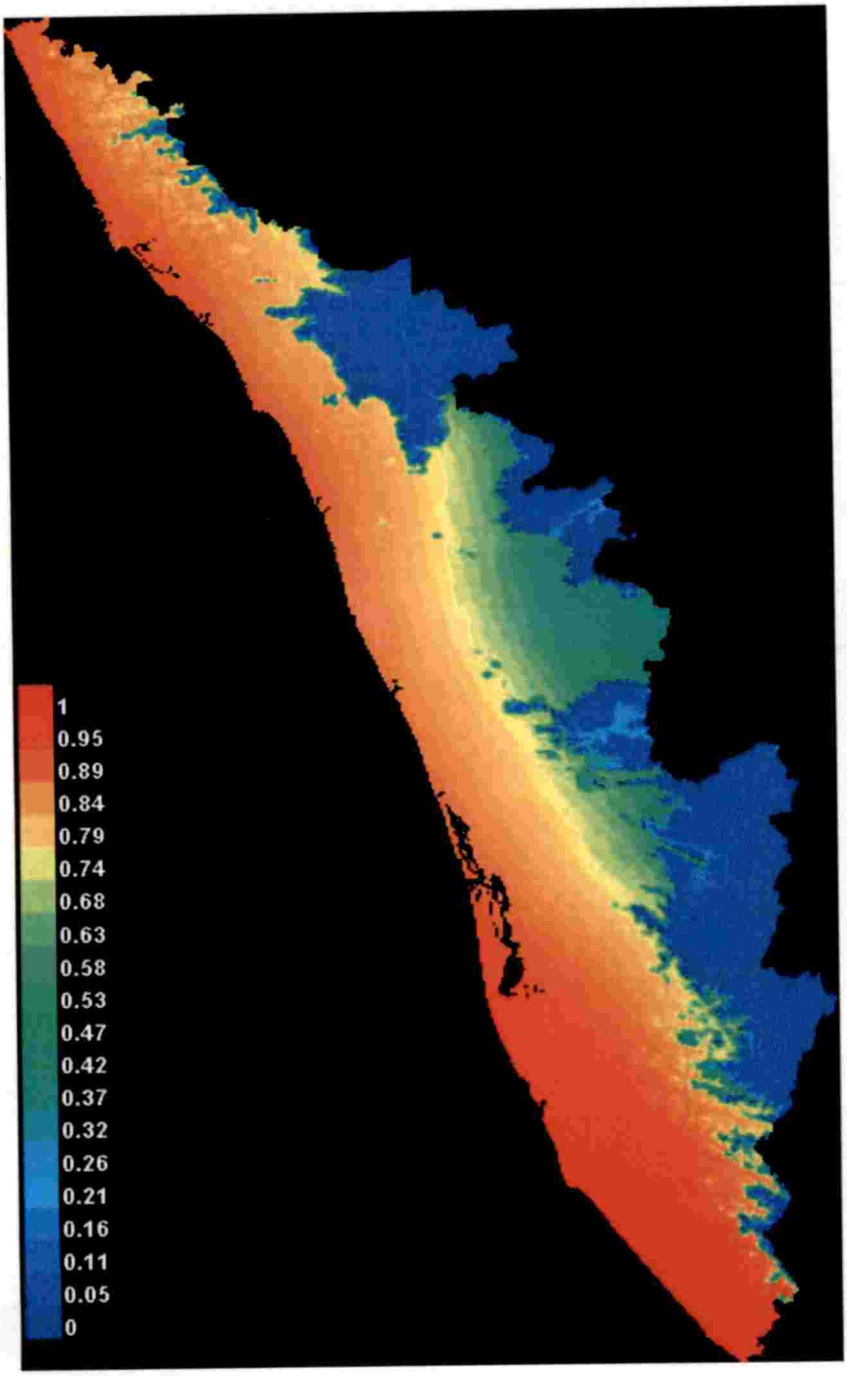


Fig. 8. Prediction of the future distribution of the Black-headed Bunting for 2050 under RCP4.5 prediction

61

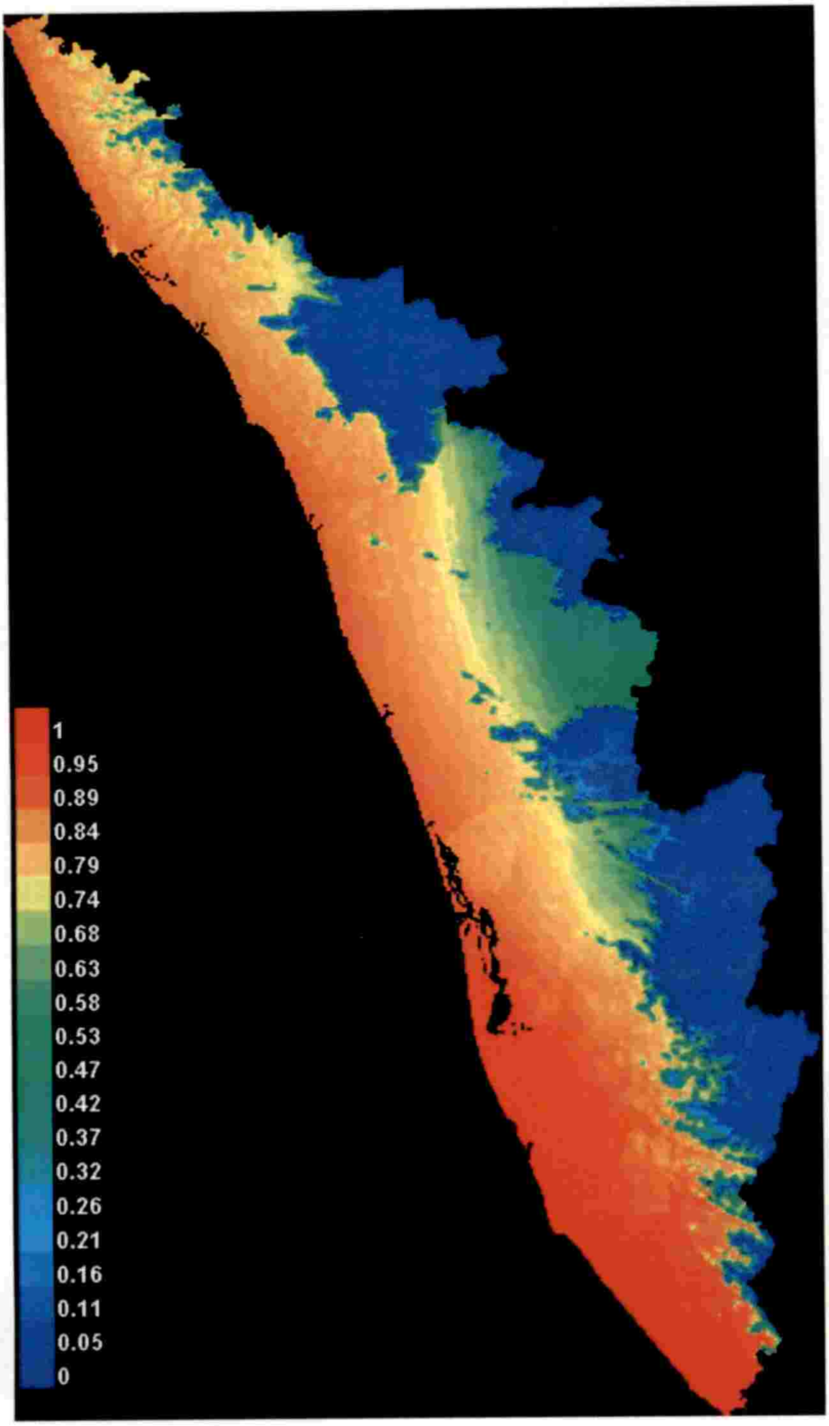


Fig. 9. Prediction of the future distribution of the Black-headed Bunting for 2050 under RCP6.0 prediction

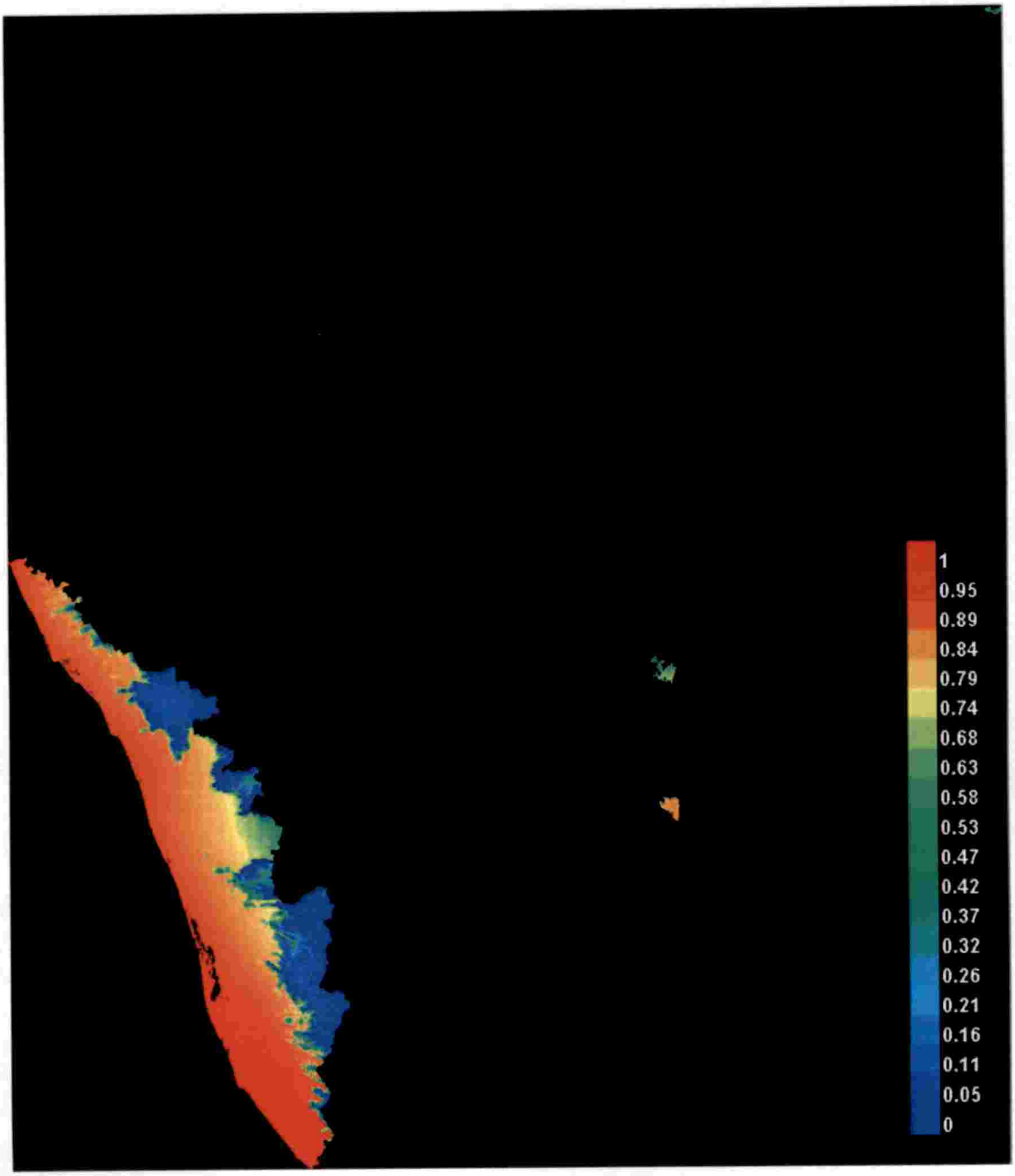


Fig. 10. Prediction of the future distribution of the Black-headed Bunting for 2050 under RCP8.5 prediction

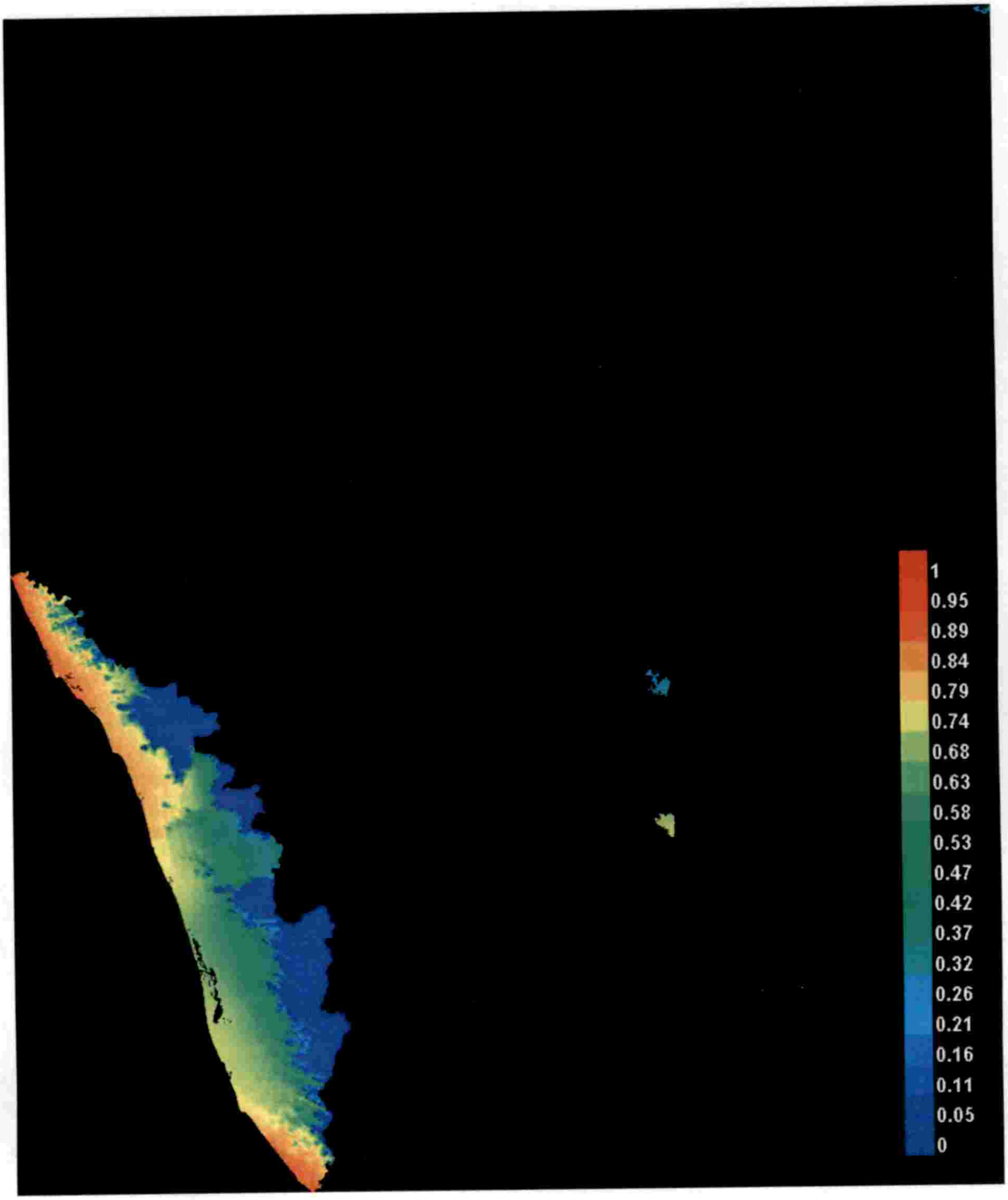


Fig. 11. Prediction of the future distribution of the Black-headed Bunting for 2070 under RCP2.6 prediction

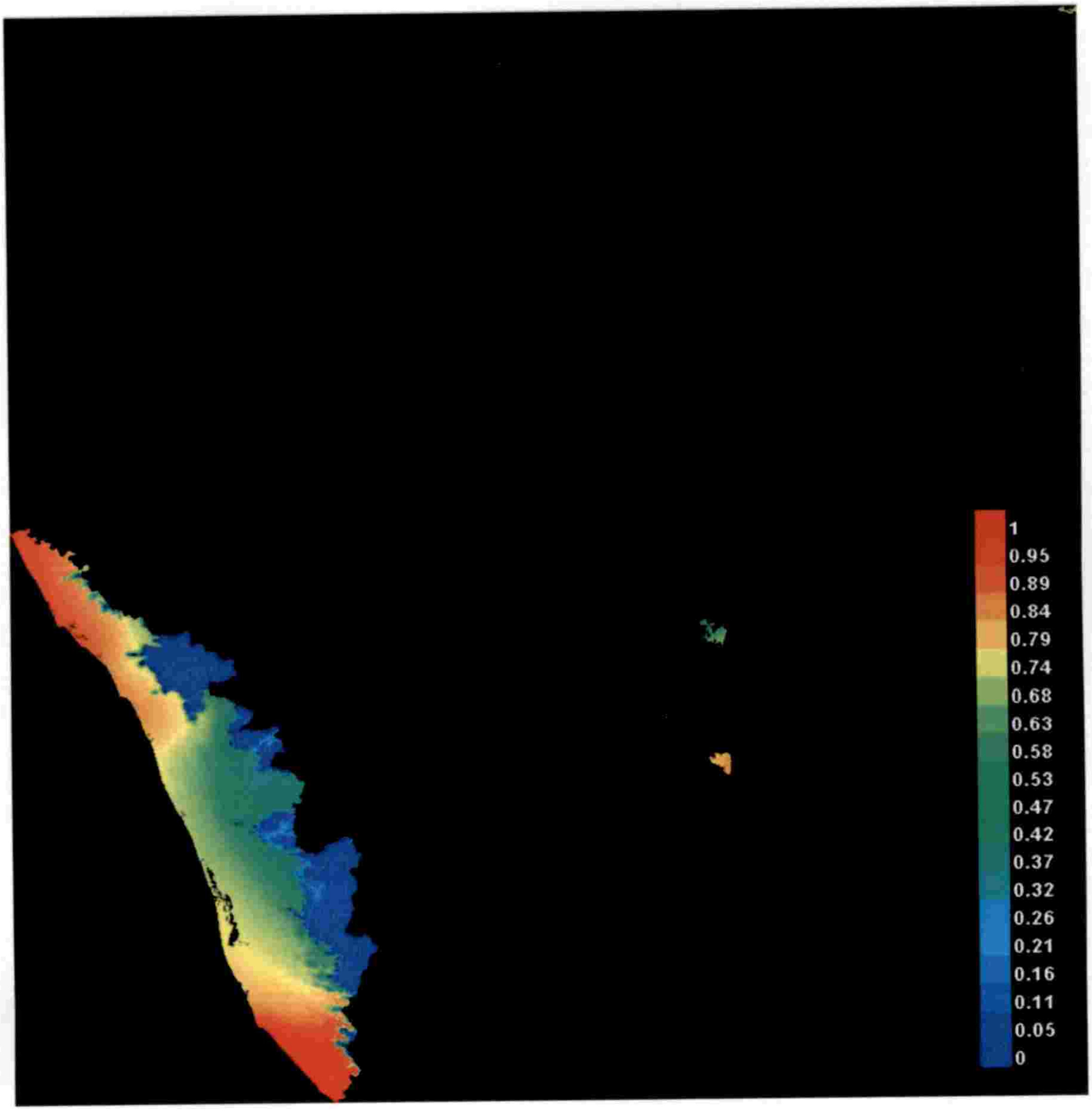


Fig. 12. Prediction of the future distribution of the Black-headed Bunting for 2070 under RCP4.5 prediction

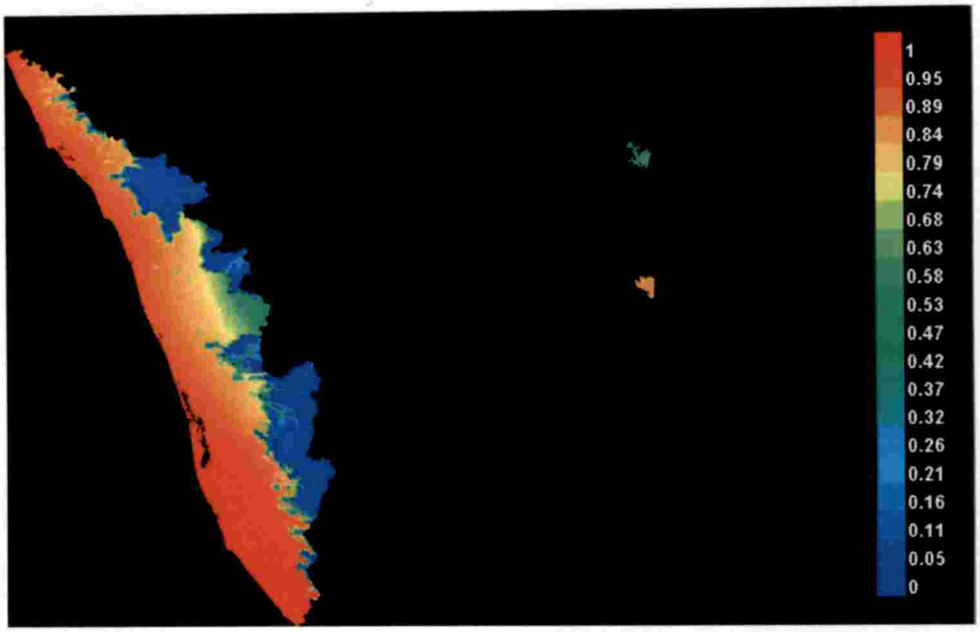


Fig. 13. Prediction of the future distribution of the Black-headed Bunting for 2070 under rcp6.0 prediction

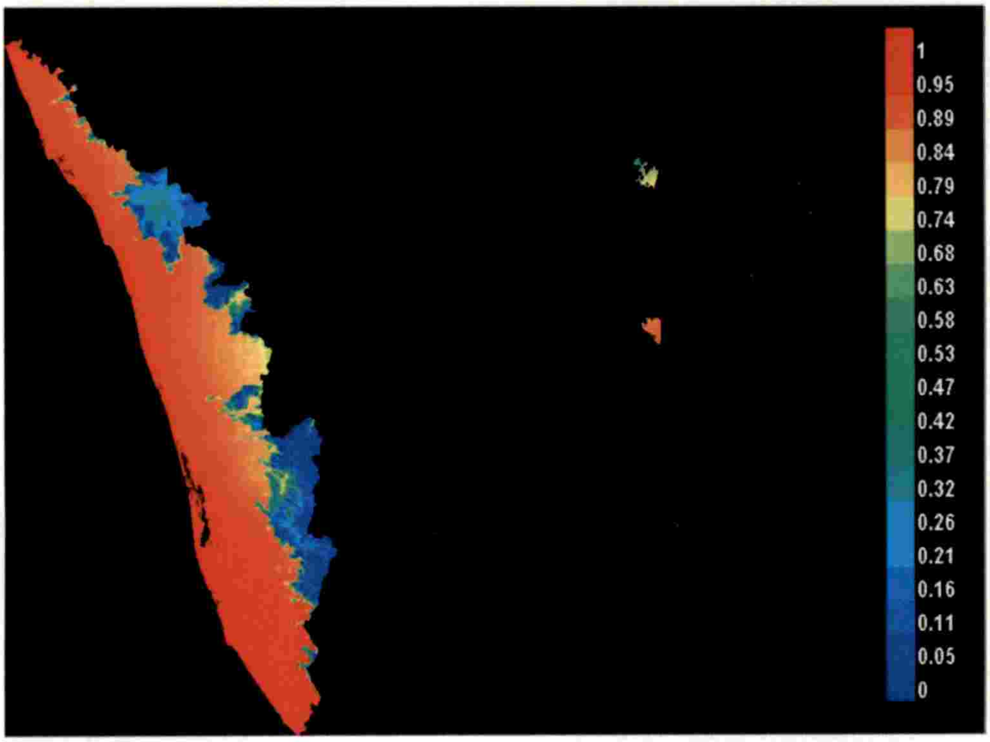


Fig. 14. Prediction of the future distribution of the Black-headed Bunting for 2070 under RCP8.5 prediction

4.4 BLUETHROAT

To select the better model for accurate results, 4 different models were run by MaxEnt and the corresponding AUC values and SD were analysed for the given bird.

Table.4. Average test AUC values and SD of each model of the distribution of the Bluethroat

Model trial no:	AUC values	SD
1	0.890	0.132
2	0.857	0.133
3	0.891	0.105
4	0.841	0.073

Here the third model was selected as the better one for the modelling of species distribution at the present time as it has the best AUC value and lower SD.

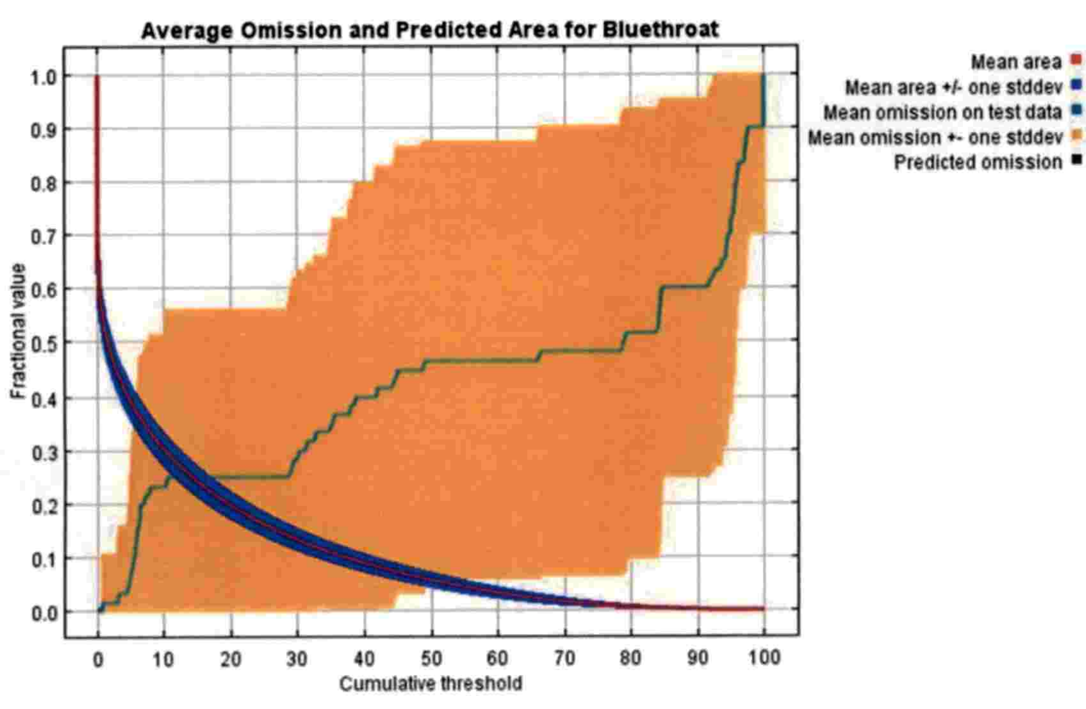


Fig. 15.shows the Test omission rate and predicted area as a function of the cumulative threshold, averaged over the replicate runs for the Bluethroat

67

Here the test omission rate does not fit correct to the model. The mean omission line is closer to the predicted omission line but does not pass through it.

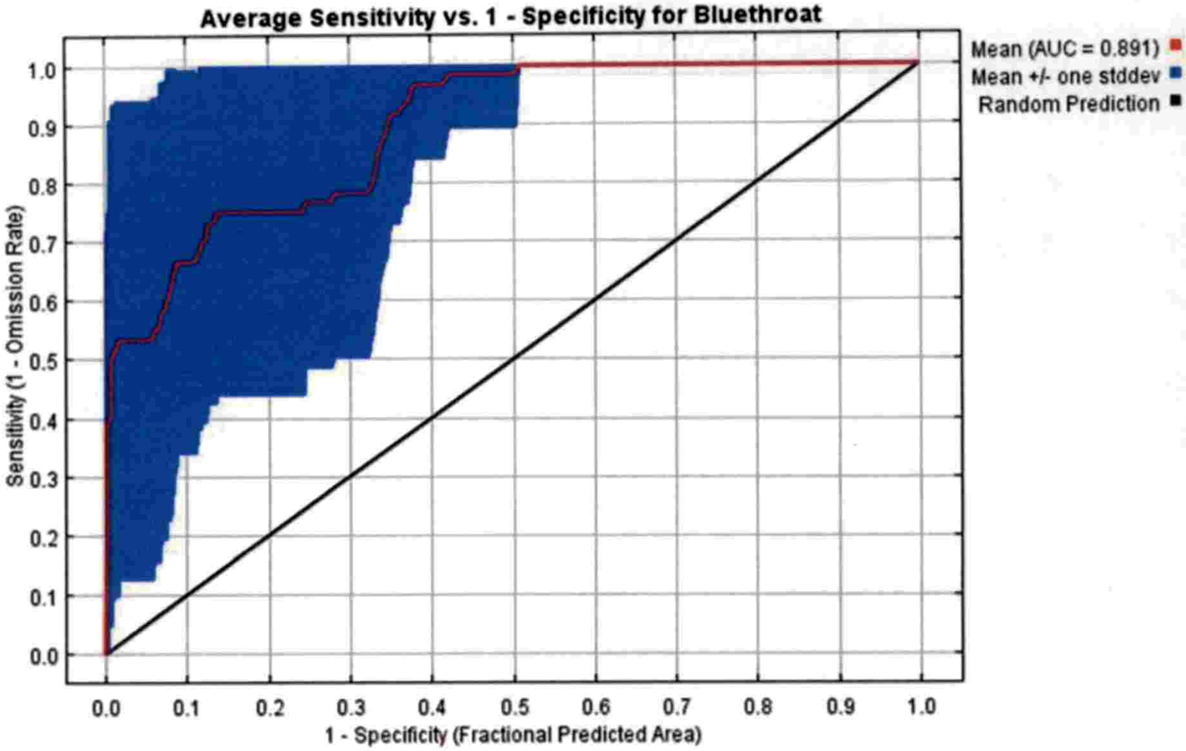
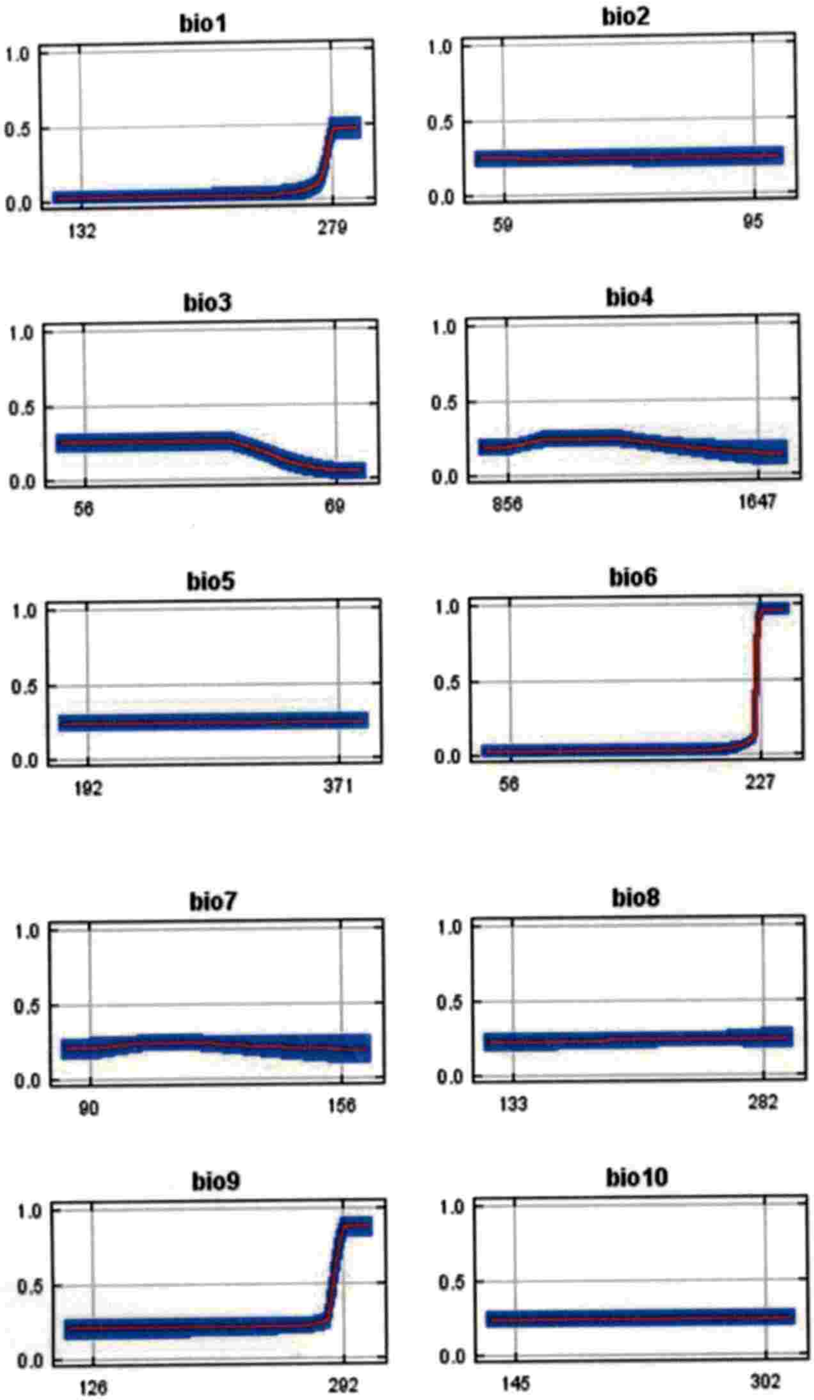


Fig. 16. Depicts the ROC curve averaged over the replicated runs of the given model of Bluethroat

Here the ROC curve passes over the random prediction line but there is no continuous path and it showed an increasing and decreasing trend.

68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0.0
132
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bio2
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0.5
0.0
59
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bio3
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0.5
0.0
56
69
bio4
1.0
0.5
0.0
856
1647
bio5
1.0
0.5
0.0
192
371
bio6
1.0
0.5
0.0
56
227
bio7
1.0
0.5
0.0
90
156
bio8
1.0
0.5
0.0
133
282
bio9
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0.5
0.0
126
292
bio10
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145
302

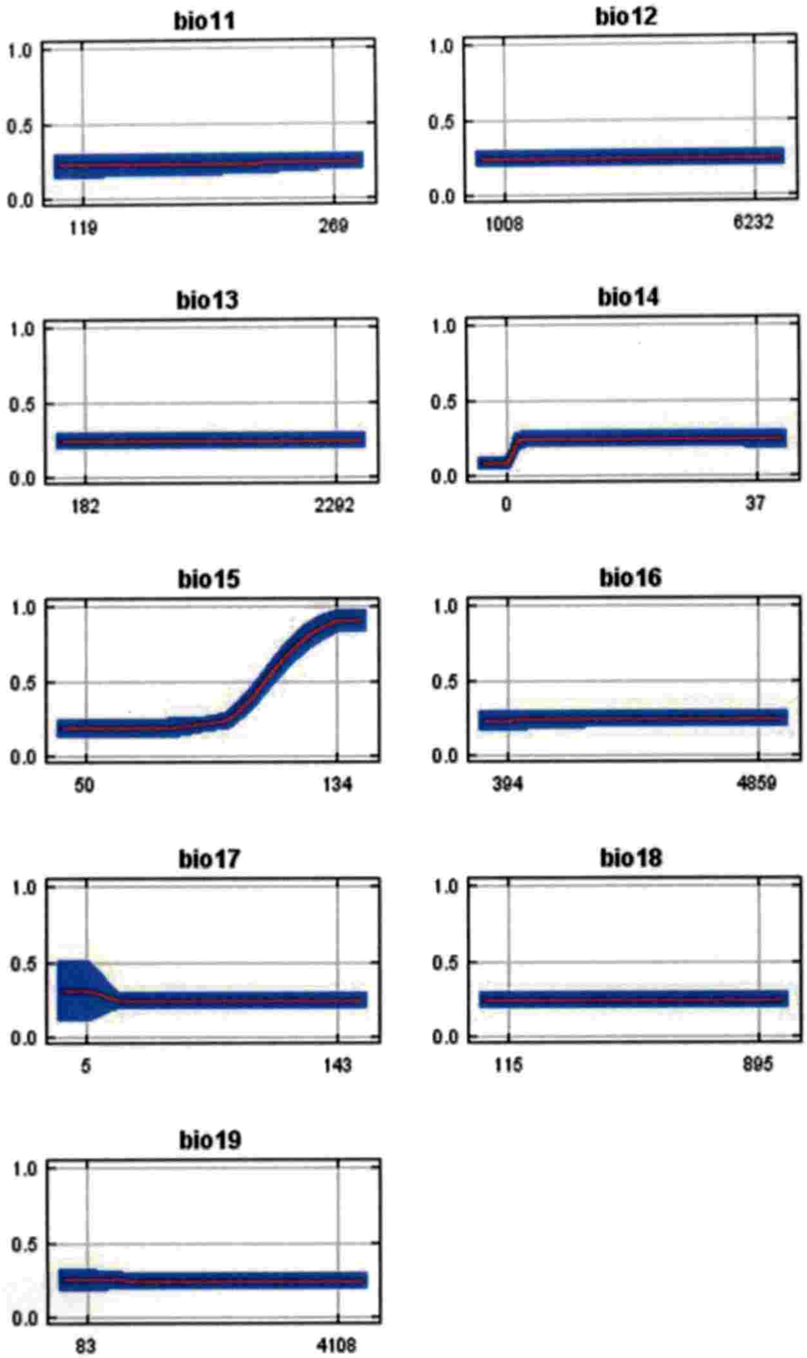
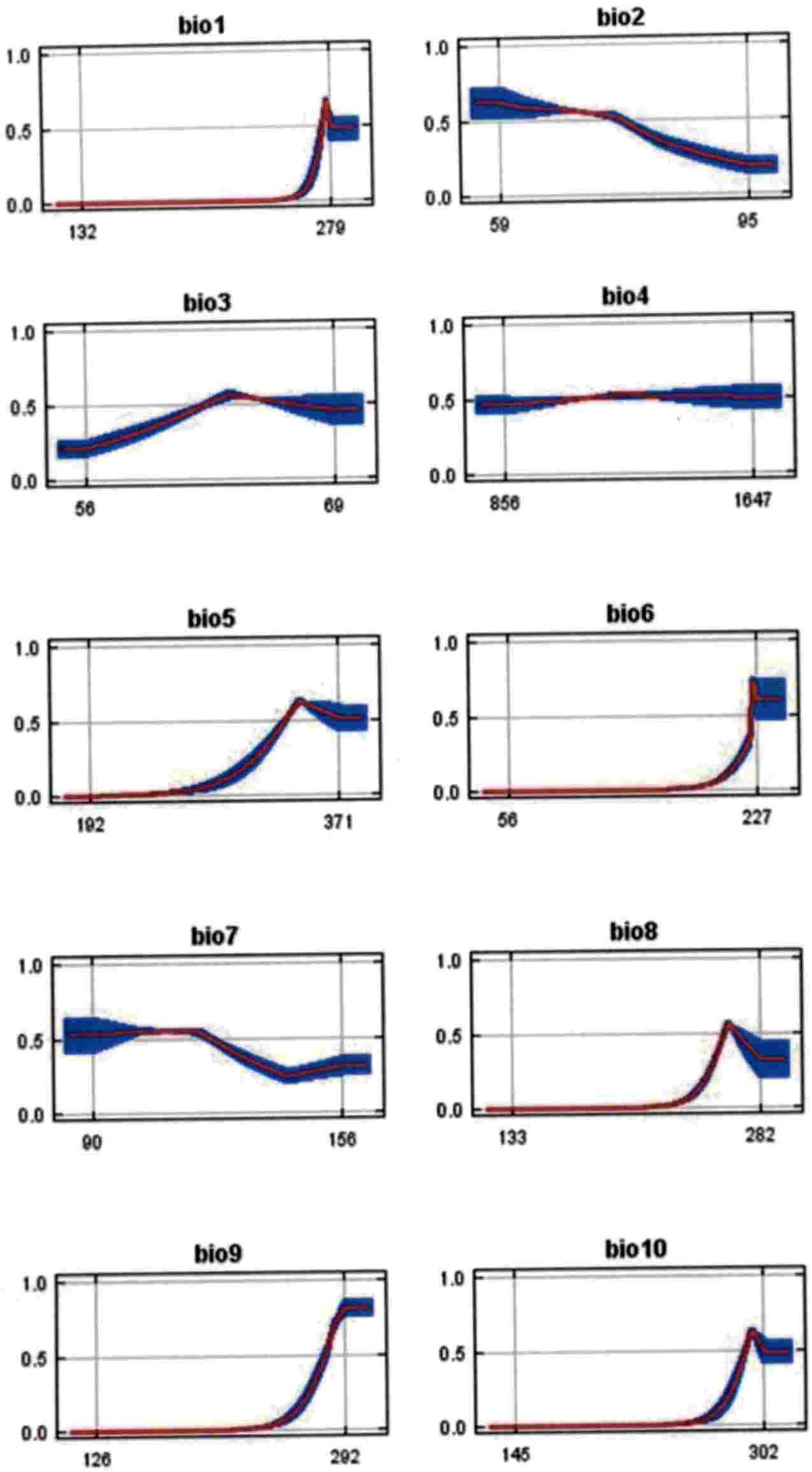


Fig. 17. Response curves of each variable in the distribution of the Bluethroat keeping all other variables at their average values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bio4
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bio5
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bio6
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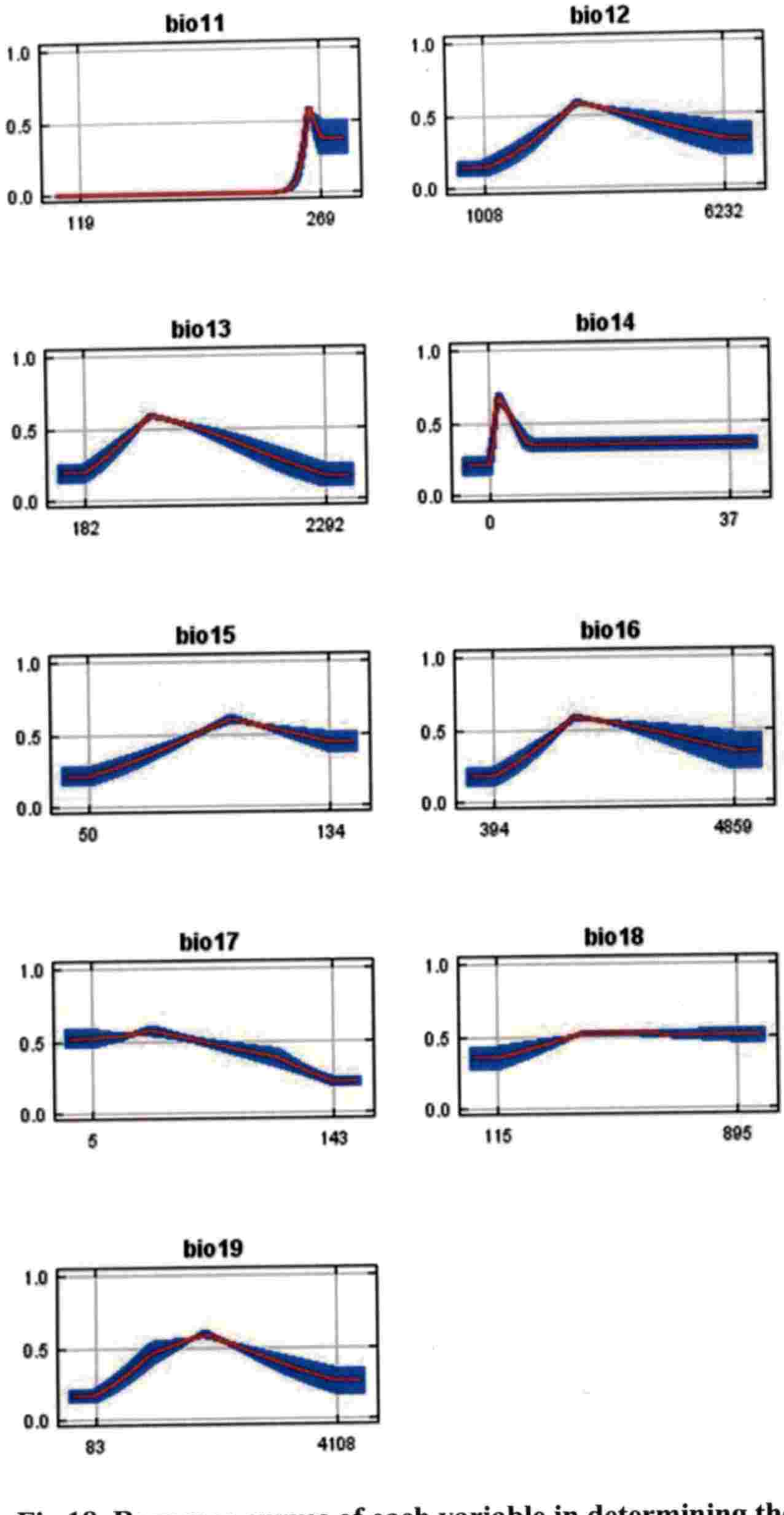

Fig.18. Response curves of each variable in determining the distribution of the Bluethroat created using only the corresponding variable

4.4.1 VARIABLE CONTRIBUTION TO THE MODEL DISTRIBUTION OF THE BLUETHROAT

Table.5. Percent contribution and permutation importance of all environmental variables to the model for the Bluethroat

Variable	Percent contribution	Permutation importance
Bio6	49.7	51.3
Bio9	26.5	3.1
Bio1	6.9	24.4
Bio14	3.8	0.5
Bio7	2.9	0.9
Bio19	2.4	0
Bio15	2.4	16.2
Bio17	2.3	0.6
Bio3	2.3	1.4
Bio11	0.5	0.2
Bio4	0.2	0.9
Bio16	0	0.2
Bio8	0	0.1
Bio10	0	0
Bio2	0	0.1
Bio12	0	0
Bio5	0	0
Bio18	0	0
Bio13	0	0

The percent contribution and permutation importance of all the environmental variables are given by the MaxEnt output and it is shown in Table.5. Among the variables the minimum temperature of the coldest month (bio6) shown a higher percent contribution of 49.7 and about eight variables like bio16, bio8, bio10, bio2, bio12, bio5, bio18, bio13 had no contribution at all. The mean temperature of the driest quarter showed a percent contribution of 26.5. Other eight variables contributed less than 10. In the case of permutation importance, bio6 showed a value of 51.3. The annual mean temperature (bio1) and the precipitation seasonality (bio15) had a permutation importance greater than 10. The variables bio2, bio8, bio16, bio4, bio11, bio3, bio17, bio7, bio14 showed the permutation importance less than 10.

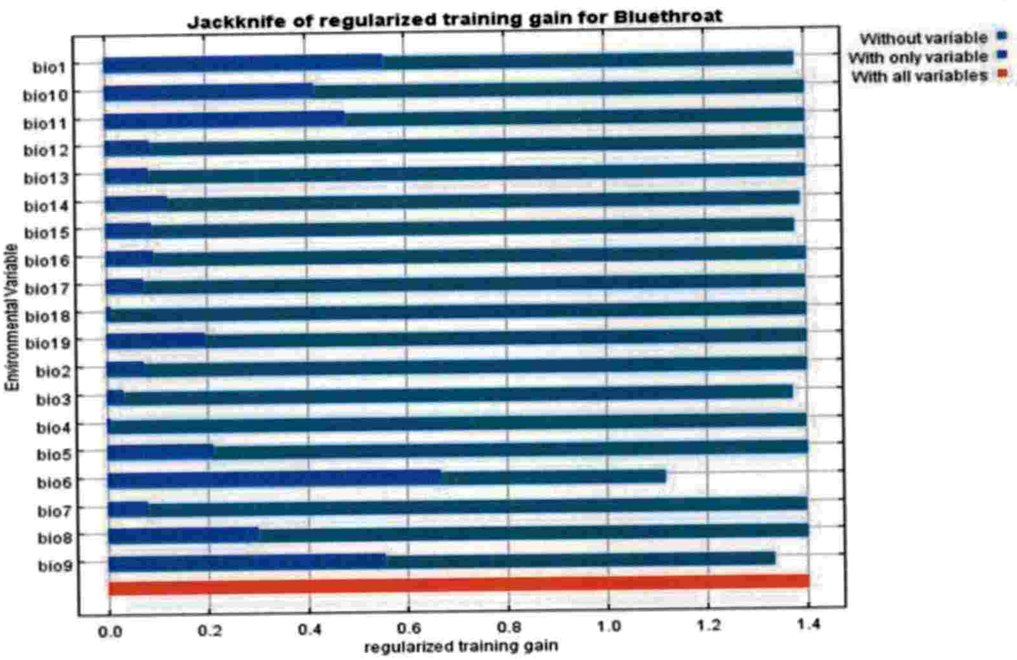

Fig. 19. Jackknife analysis of regularized training gain for the Bluethroat using all the variables

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The results of the jack-knife test of variable importance shown in Fig. 19. tell that the environmental variable with highest gain when used in isolation is bio6, which therefore appears to have the most useful information by itself. The variables bio1 and bio9 lies very next to bio6 while considering the gain. The environmental variable that decreases the gain the most when it is omitted is bio6, which therefore appears to have the most information that isn't present in the other variables.

The response curves from the MaxEnt output (Fig.17) are the curves with logistic prediction changes as each environmental variable has varied, keeping all other environmental variables at their average sample value. Positive responses are shown higher by bio1, bio6, bio9 and bio15. Remaining all other variables showed less significance below 50 percent probability.

The response curves from the MaxEnt output (Fig. 18) showed the change in predicted probability when the corresponding variable is only used. Positive response was shown by bio8 and bio9. At the same time bio4, bio3, bio5 and bio 10 showed moderate significance. All the remaining variables showed no particular importance for the existence of the species.

4.4.2Current and future predictions of the distribution of Bluethroat

The current distribution pattern depicted in Fig. 20. showed the abundance of the Bluethroat in the midlands of Thrissur. Also the presence was observed on some parts of high lands of Palakkad, low lands of Thiruvananthapuram and low lands of Alappuzha. There were presences of Bluethroat with a probability greater than 50 percent in the low lands of Kannur, Kasargode, Alappuzha and Thrissur.

The predicted distribution of the Bluethroat in 2050 under the RCP 2.6model is given in Fig.21. There would be a richer abundance of distribution of Bluethroat in the low lands and mid lands of Thiruvananthapuram, low lands and mid lands of Kollam, low lands of Alappuzha, low lands and mid lands of Pathanamthitta, low lands of Kottayam, low and mid lands of Ernakulam, mid lands and high lands of

Palakkad, low lands and mid lands of Thrissur, low lands, mid lands and high lands of Malappuram, low lands and mid lands of Kozhikode, Kannur and Kasargode.

The predicted distribution of the Bluethroat in 2050 under the RCP4.5 model is given in Fig. 22. This is almost similar to the 2050 RCP2.6 model. There would be a stronger abundance of distribution of Bluethroat in the low lands and mid lands of Thiruvananthapuram, low lands and mid lands of Kollam.

The predicted distribution of the Bluethroat in 2050 under the RCP6.0 model is given in Fig. 23. The expansion of distribution of the Bluethroat would be much greater in the low lands and some parts of high lands of Thiruvananthapuram, low lands and some regions of high lands of Kollam, some regions of mid lands and low lands of Pathanamthitta, low lands , middle lands and high lands of Kottayam, low lands of Alappuzha, low lands and mid lands of Ernakulam, low lands and mid lands of Thrissur, low lands , mid lands and some areas of high lands of Palakkad, low and middle lands of Malappuram, low lands, mid lands and high lands of Kozhikode, low lands and mid lands of Kannur and Kasargode. There would be the presence of distribution of Bluethroat in the midlands of Kollam, Thiruvananthapuram and Palakkad with a probability of 0.84.

The predicted distribution of the Bluethroat in 2050 under the RCP8.5 model is given in Fig. 24. According to the model, the abundance of distribution of Bluethroat would be stronger in the low lands, mid lands and high lands of Kasargode, low lands, mid lands and high lands of Malappuram, low lands, mid lands and some parts of high lands of Palakkad, low lands, mid lands and high lands of Thrissur, low lands, mid lands and high lands of Ernakulam, low lands and mid lands of Kottayam, low lands of Alappuzha, low lands and mid lands of Pathanamthitta, low lands, mid lands and high lands of Thiruvananthapuram and Kollam.

The predicted distribution of Bluethroat in 2070 under the RCP 2.6 model is depicted in Fig. 25. The presence of Bluethroat would be expanding to the lowlands of Kasargode and Kannur, low lands and mid lands of Kozhikode, low lands, mid lands and high lands of Malappuram, mid lands and some regions of high lands of Palakkad, low lands and midlands of Thrissur, low lands and mid lands of Ernakulam, low lands of Alappuzha, mid and high lands of Kottayam, mid lands of Pathanamthitta, low and mid lands of Kollam and Thiruvananthapuram.

The predicted distribution of the Bluethroat in 2070 under the RCP 4.5 model is depicted in Fig. 26. The distribution of Bluethroat would be expanding to the districts of Thiruvananthapuram, Kollam, low lands of Alappuzha, mid lands of Pathanamthitta, mid lands and high lands of Kottayam, high lands of Idukki, low lands, mid lands and high lands of Ernakulam, Malappuram and Thrissur, mid lands and high lands of Palakkad, low and mid lands of Kozhikode, Kannur and Kasargode.

The predicted distribution of the Bluethroat in 2070 under the RCP 6.0 model is given in Fig. 27. Here the model predicts that the bird distribution would spread to low, mid and high lands of Thiruvananthapuram and Kollam, low lands of Alappuzha, midlands of Pathanamthitta, midlands and high lands of Kottayam, low lands, mid lands and high lands of Ernakulam and Thrissur, Mid lands and high lands of Palakkad, low lands and mid lands of Kozhikode, Kannur and Kasargode, low lands, mid lands and high lands of Malappuram.

The predicted distribution of the Bluethroat in 2070 under the RCP 8.5 model is depicted in Fig. 28. According to the model the bird distribution would spread strongly to the low lands and mid lands of Kollam and Thiruvananthapuram, low lands of Alappuzha, midlands of Pathanamthitta, midlands and high lands of Kottayam, low lands, mid lands and high lands of Ernakulam and Thrissur, Mid lands and high lands of Palakkad, low lands and mid lands of Kozhikode, Kannur and Kasargode, low lands, mid lands and high lands of Malappuram.

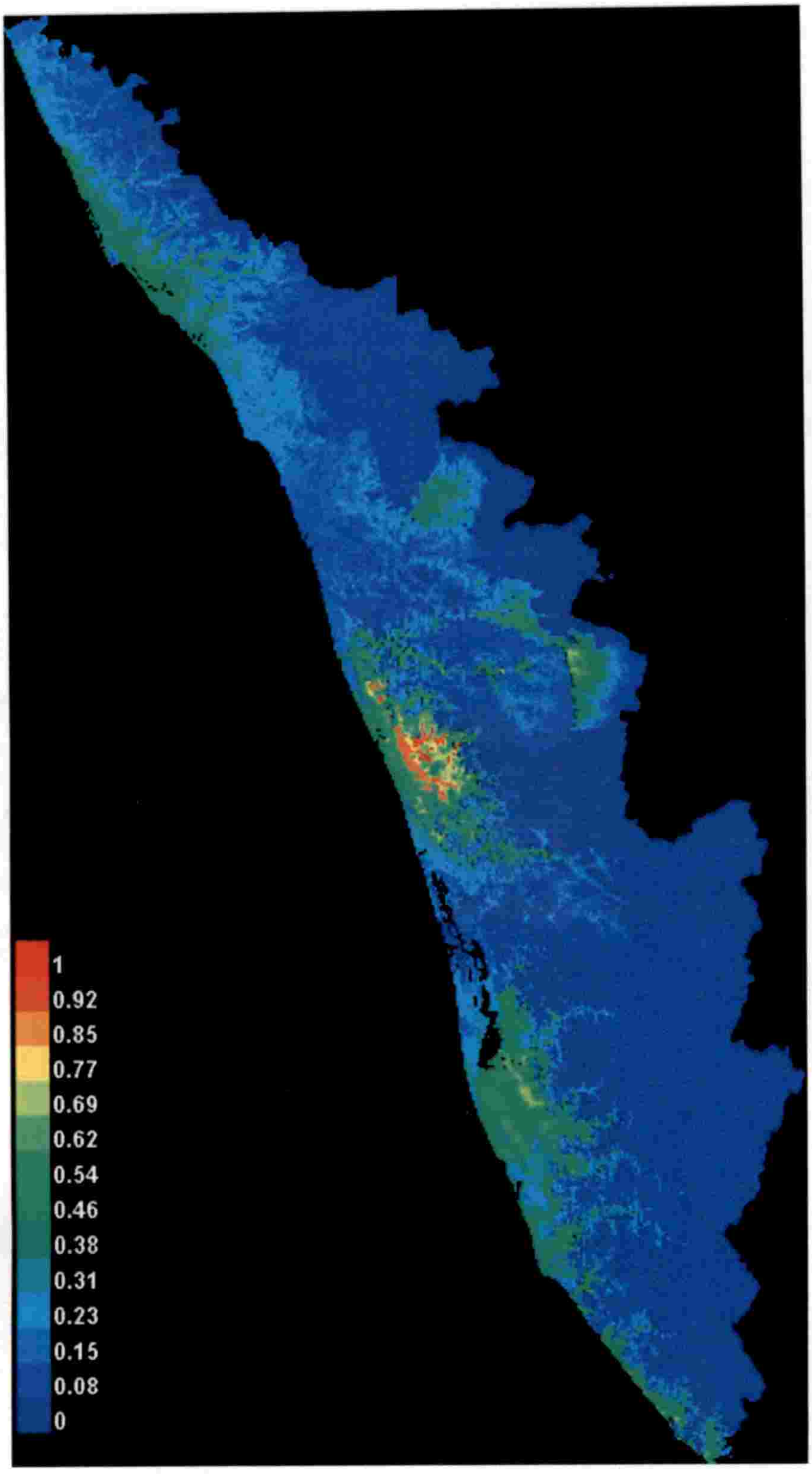

Fig.20.Current distribution of Bluethroat in Kerala

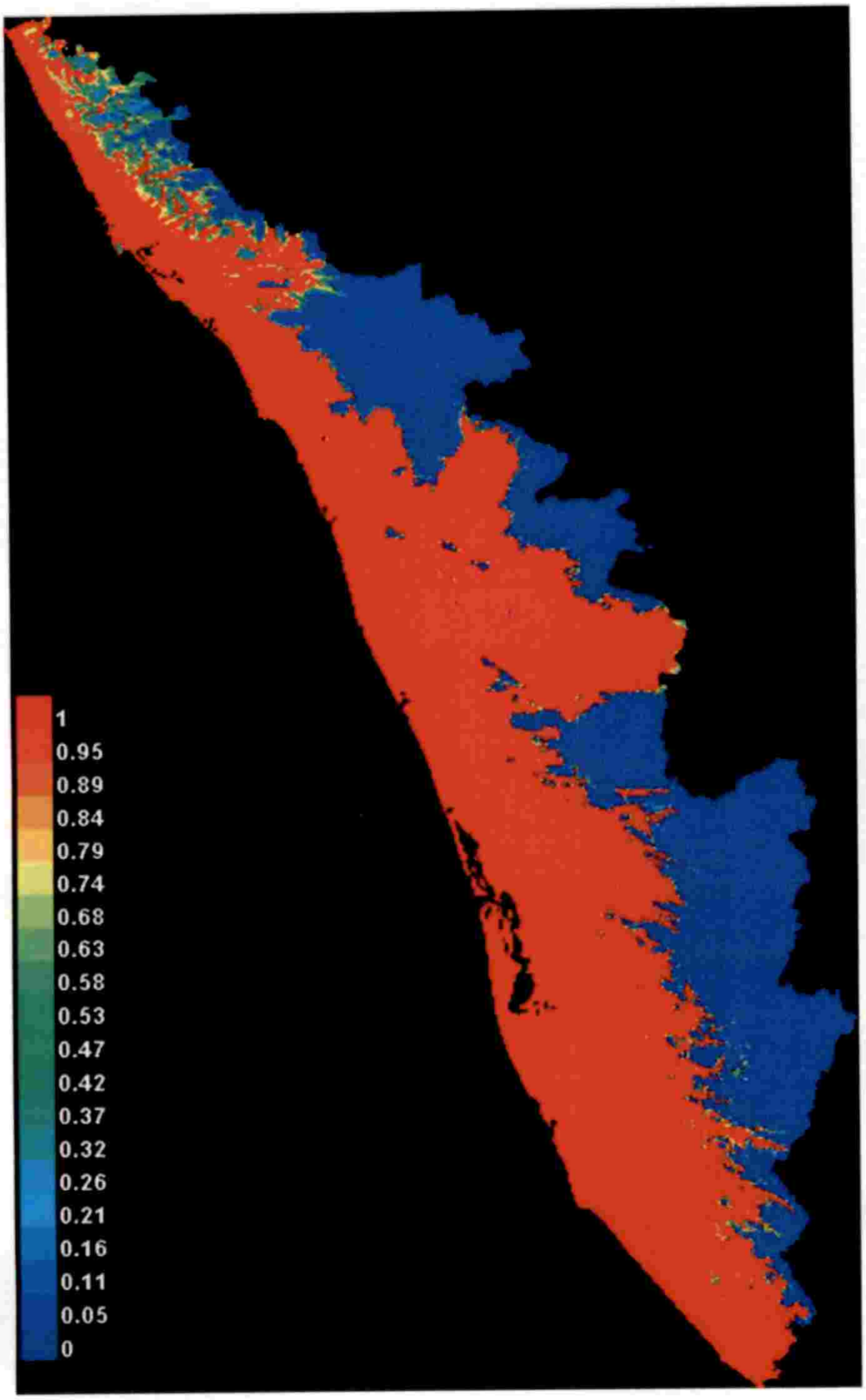

Fig.21. Prediction of the future distribution of the Bluethroatfor 2050 under RCP2.6 prediction

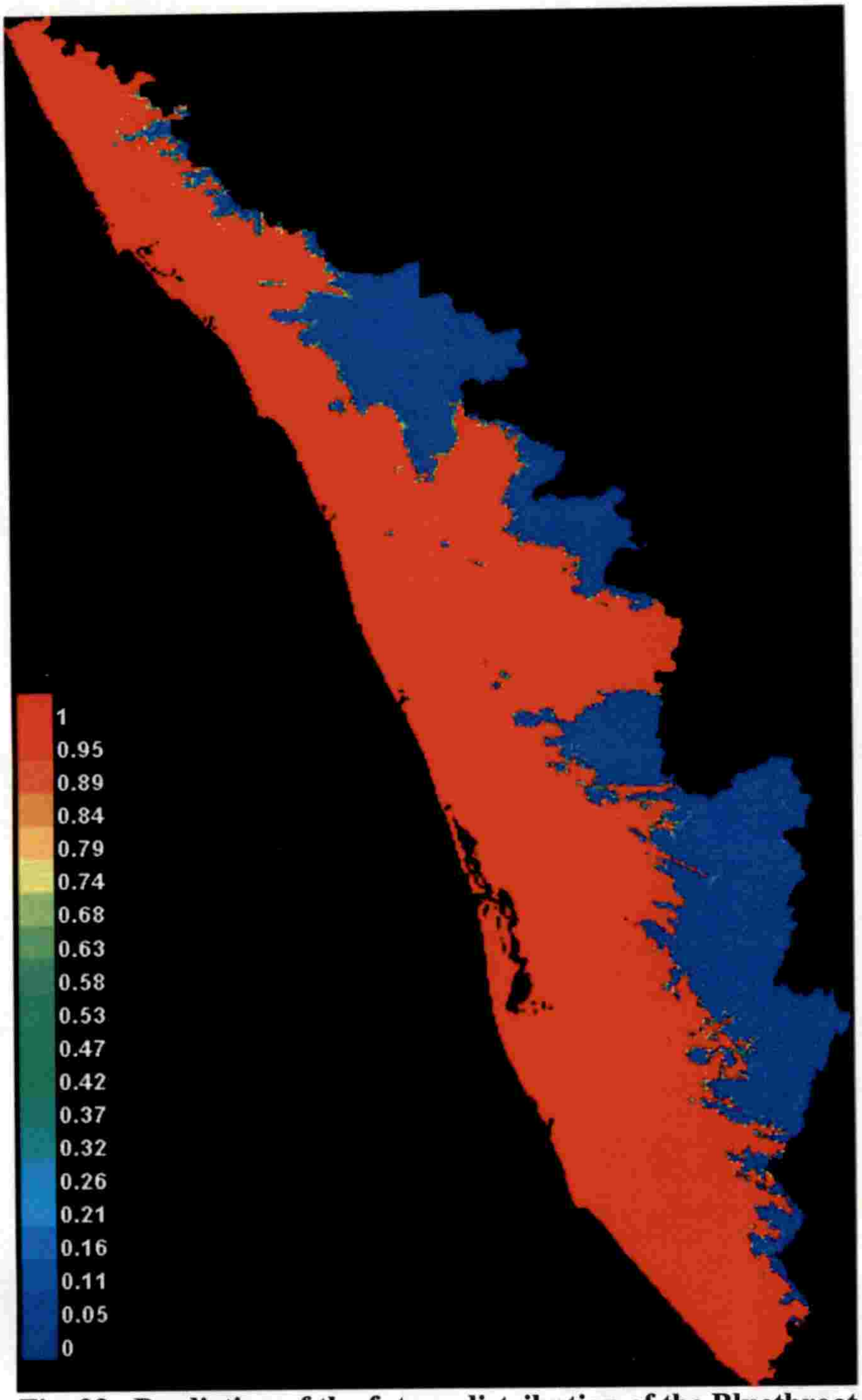

Fig. 22. Prediction of the future distribution of the Bluethroat for 2050 under RCP4.5 prediction

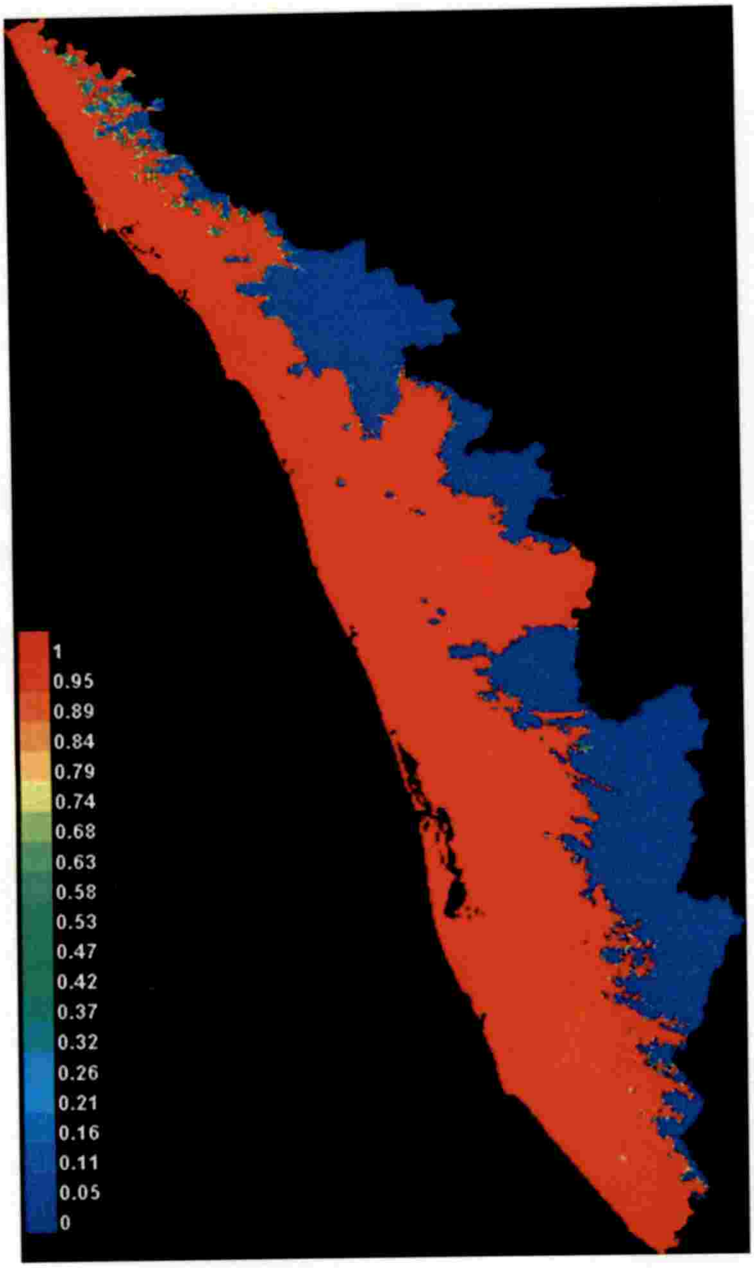

Fig. 23. Prediction of the future distribution of the Bluethroat for 2050 under rcp6.0 prediction

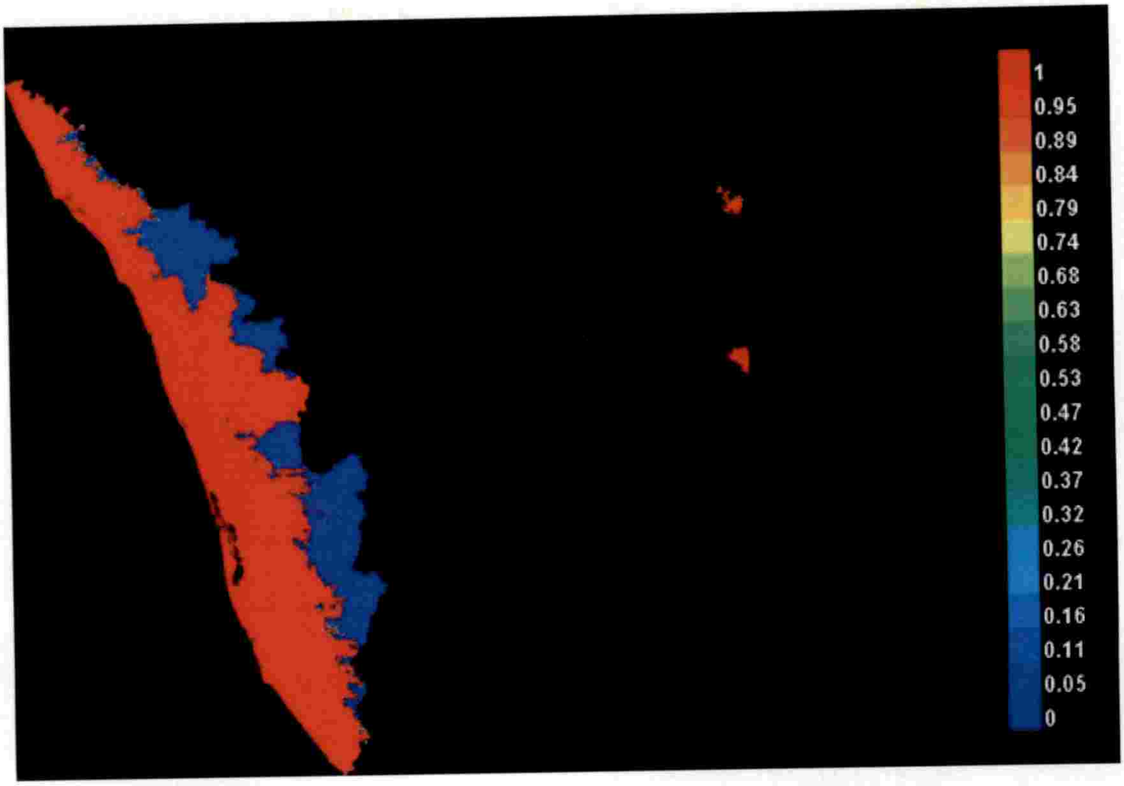

Fig. 24. Prediction of the future distribution of the Bluethroat for 2050 under RCP 8.5 prediction

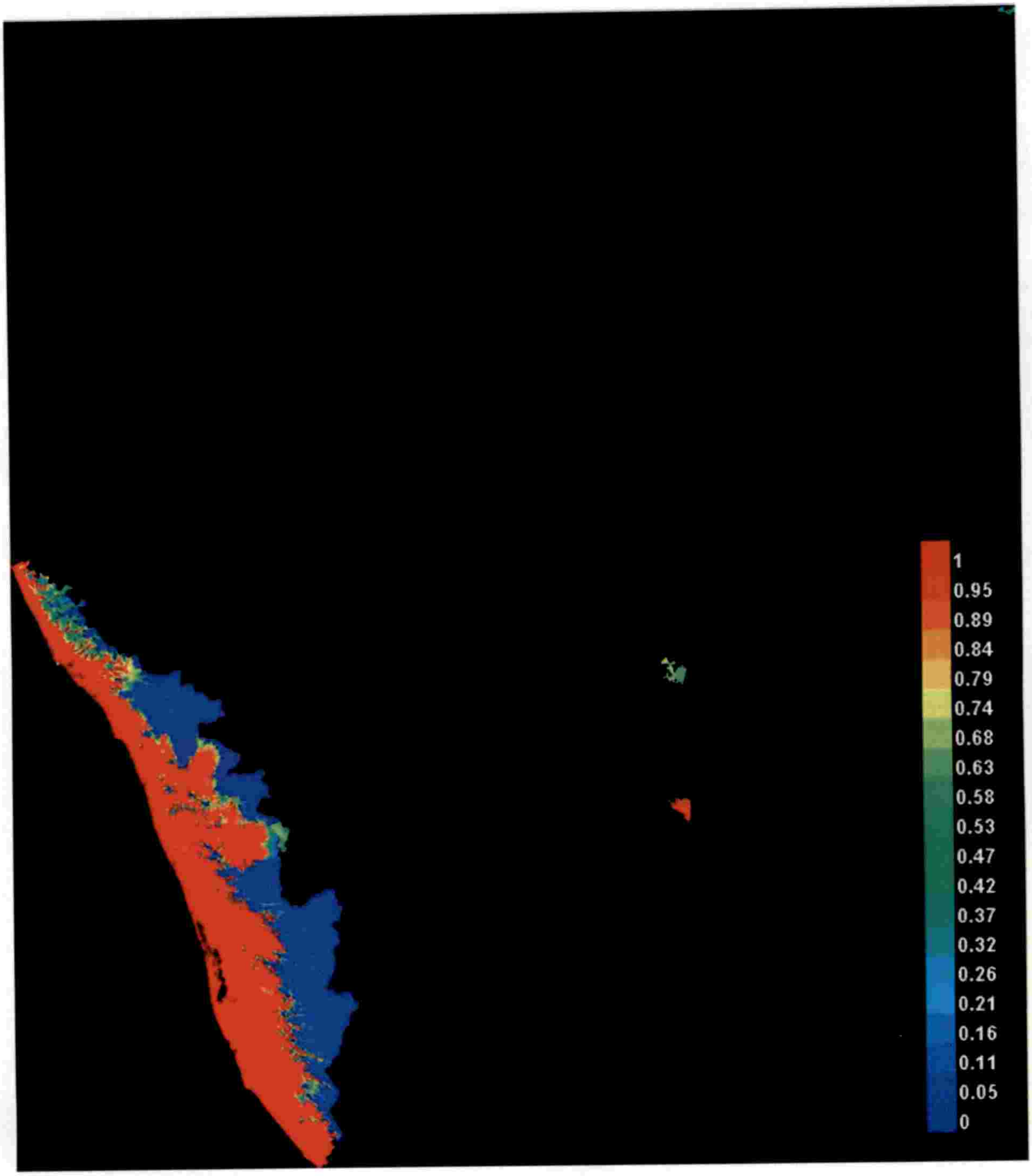

Fig. 25. Prediction of the future distribution of the Bluethroat for 2070 under RCP 2.6 prediction

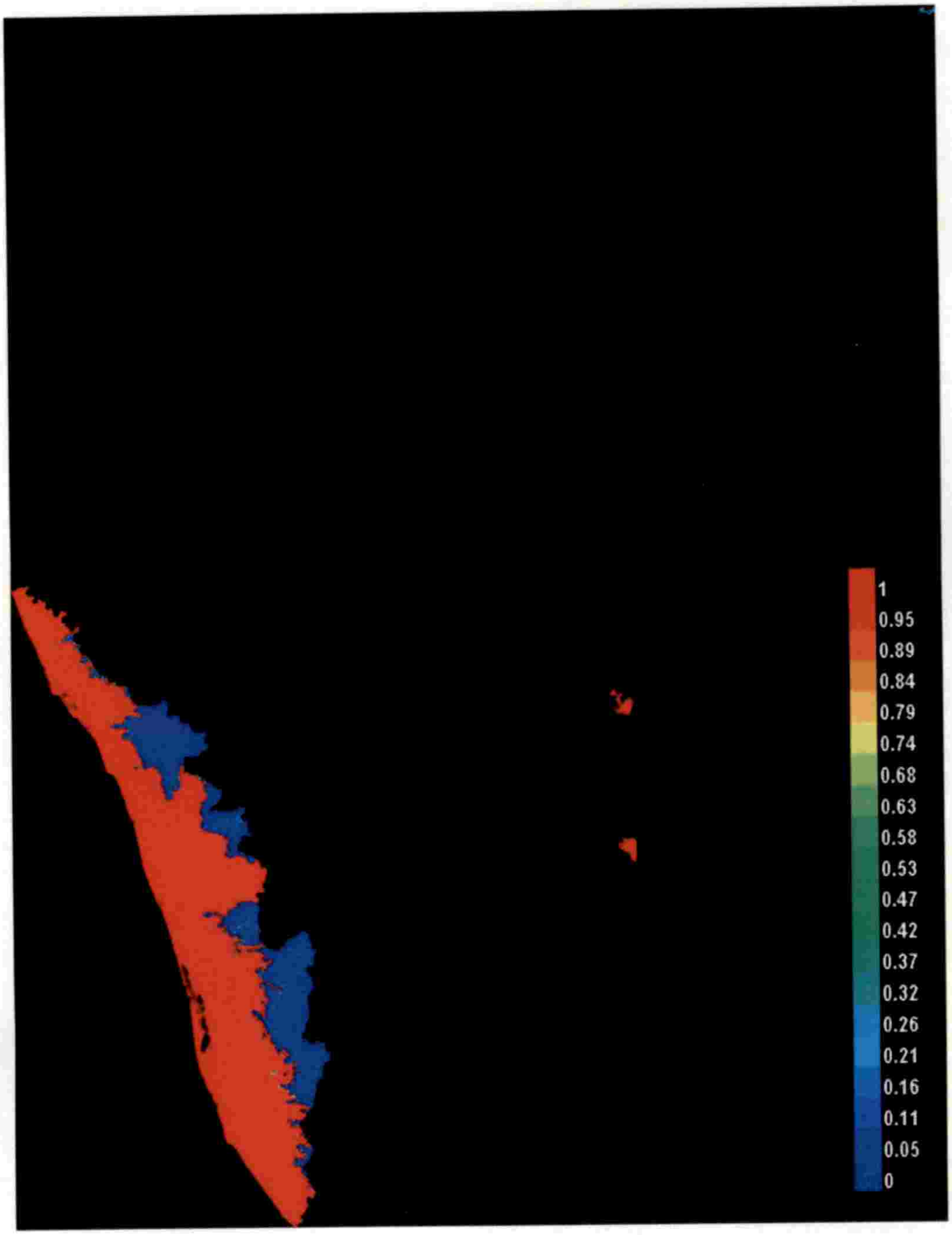

Fig.26. Prediction of the future distribution of the Bluethroat for 2070 under RCP 4.5 prediction

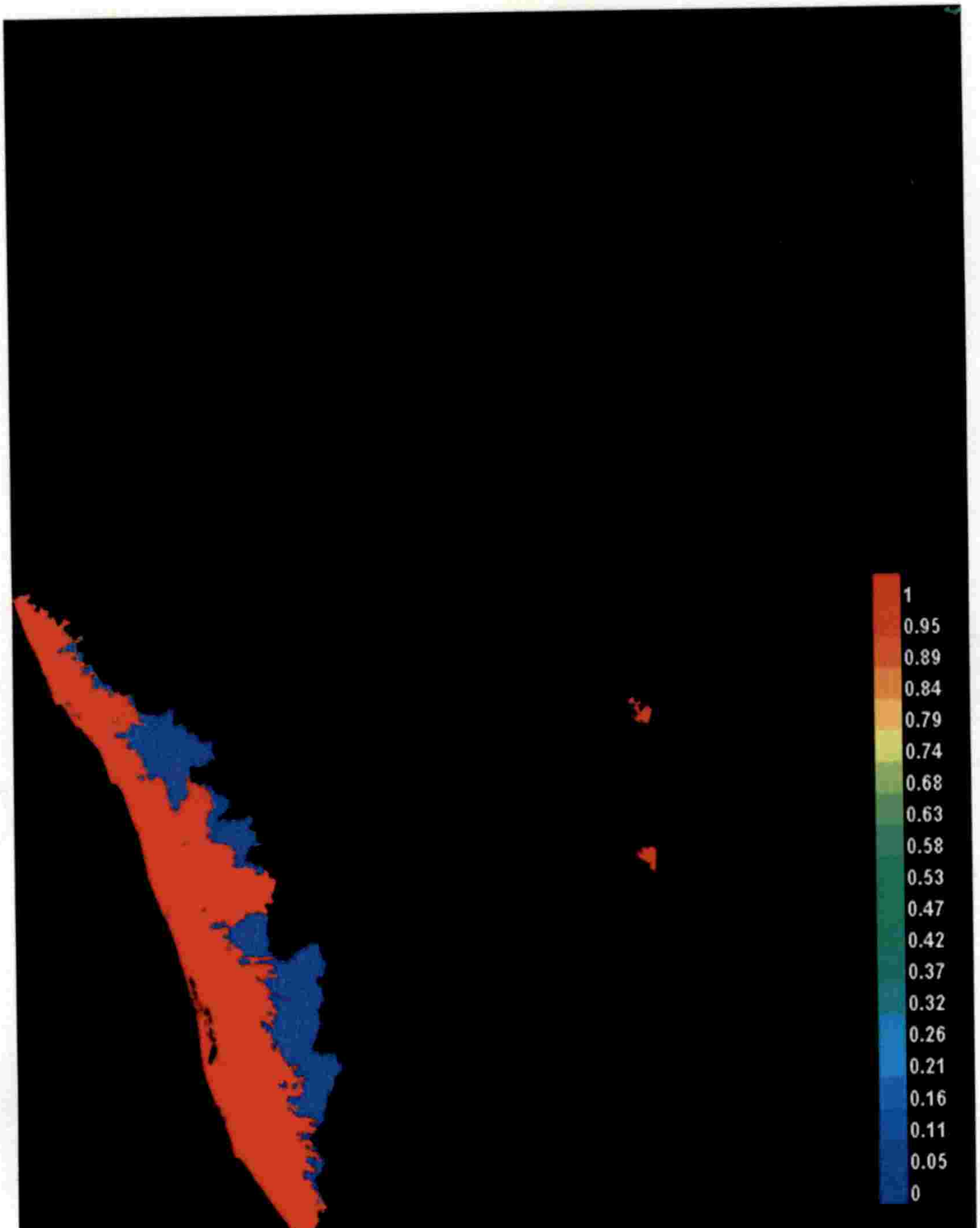

Fig. 27.Prediction of the future distribution of the Bluethroat for 2070 under RCP6.0 prediction

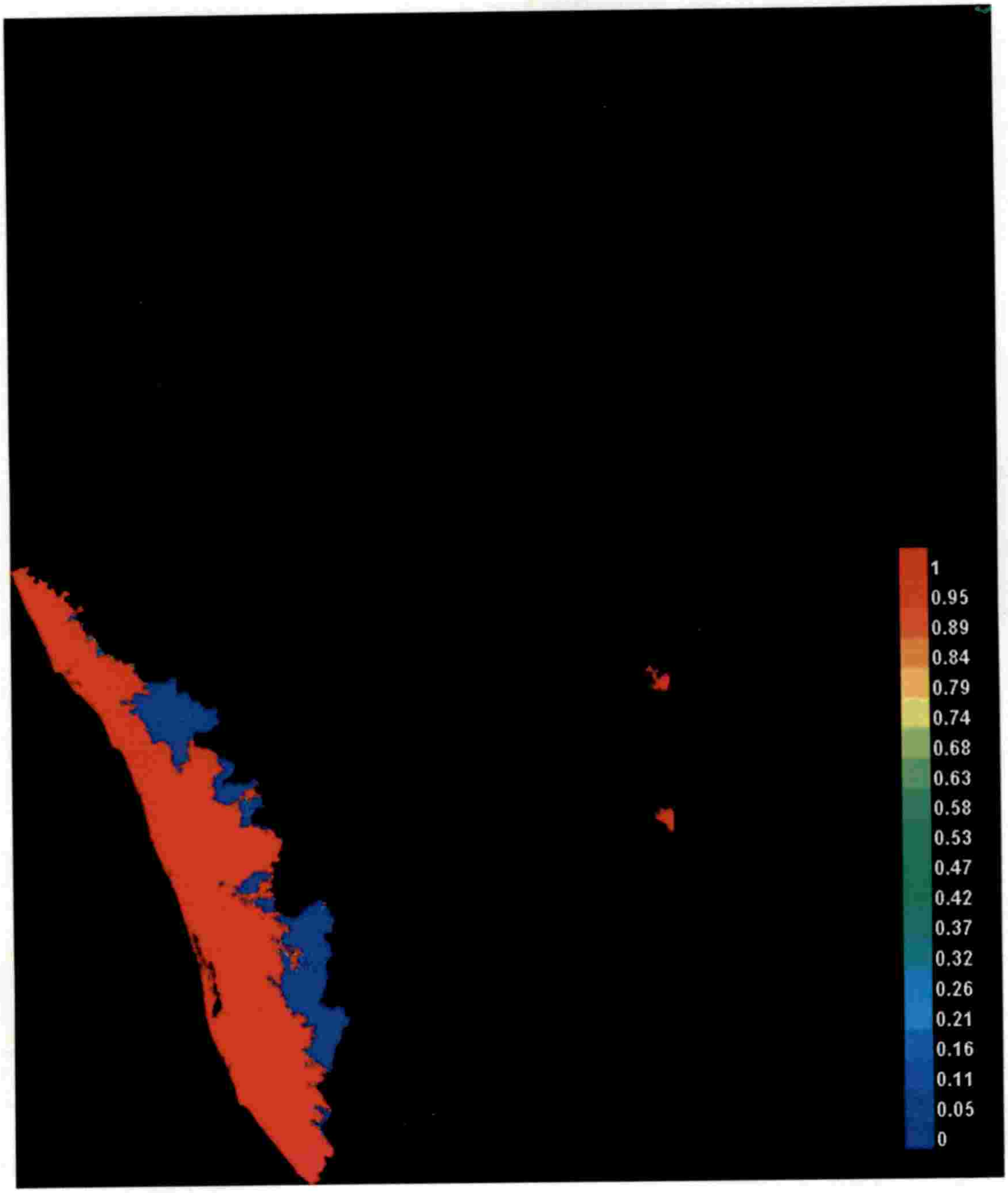

Fig. 28.Prediction of the future distribution of the Bluethroat for 2070 under RCP8.5

4.3 GRAY-HEADED LAPWING

To select the better model for accurate results, 4 different models were run by MaxEnt and the corresponding AUC values and SD were analysed for the given bird.

Table. 6. Average test AUC values and SD of each model of the distribution of the Gray-headed Lapwing

Model trial no:	AUC values	SD
1	0.924	0.050
2	0.933	0.028
3	0.935	0.040
4	0.923	0.030

Here the third model was selected as the better one for the modelling of species distribution at the present. Here, even though the SD is greater than second and fourth model, AUC value is highest for the third one.

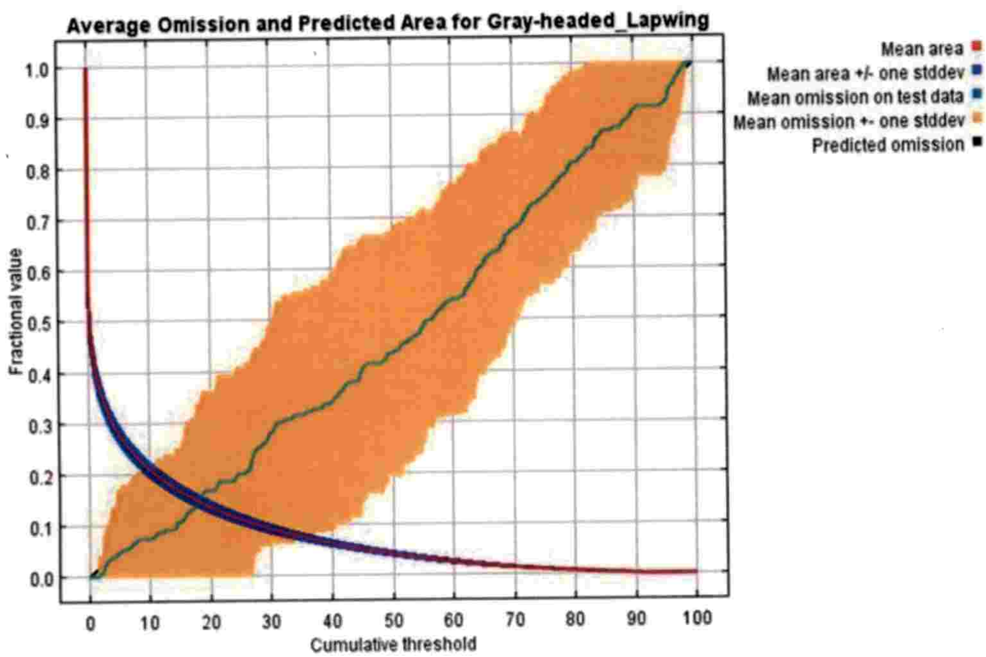

Figure.29. Shows the Test omission rate and predicted area as a function of the cumulative threshold, averaged over the replicate runs for the Gray-headed Lapwing

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Here the test omission rate fits well with the model. The mean omission line was almost passing through the predicted omission line.

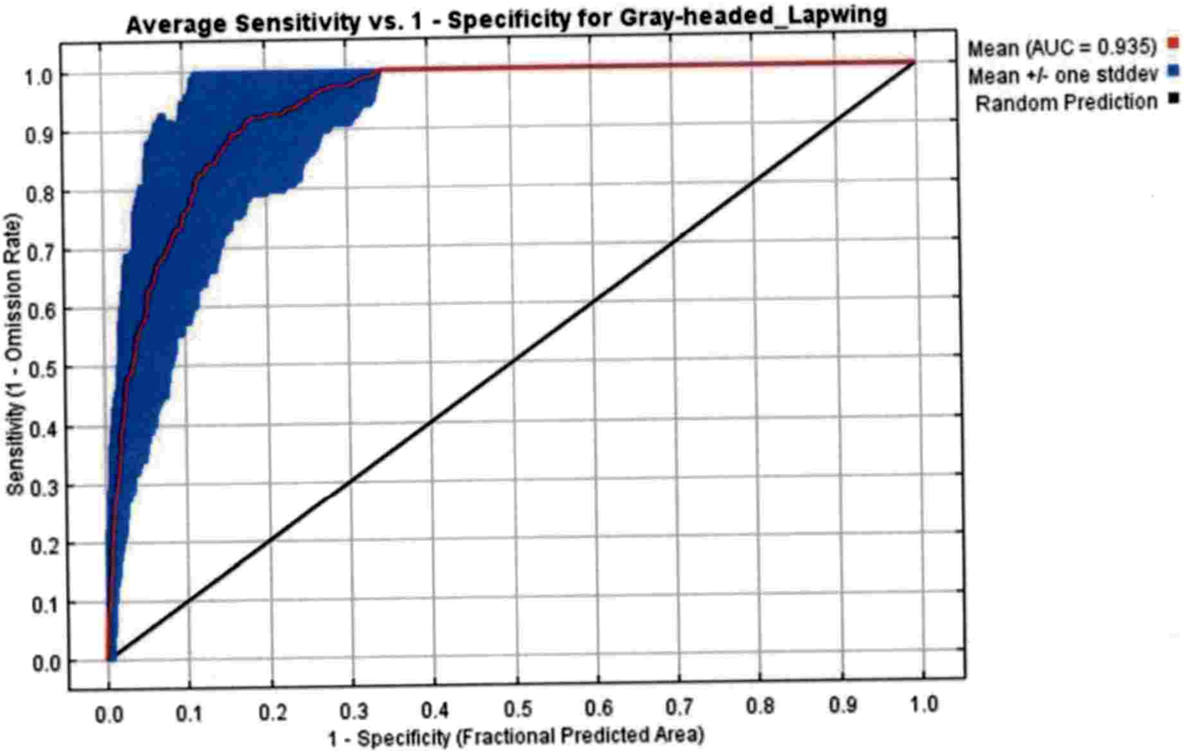
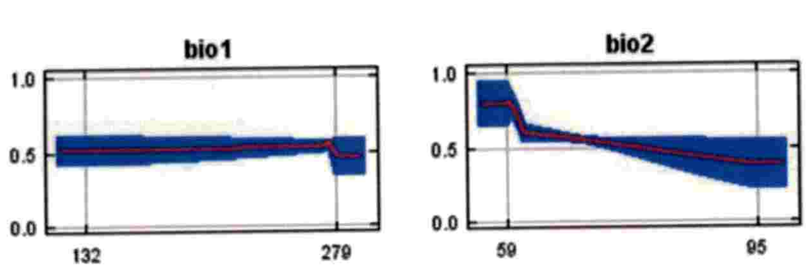


Fig.30. depicts the ROC curve averaged over the replicated runs of the given model for Gray-headed Lapwing

Here the ROC curve showed a continuous trend and passed through the left top of the random prediction line.



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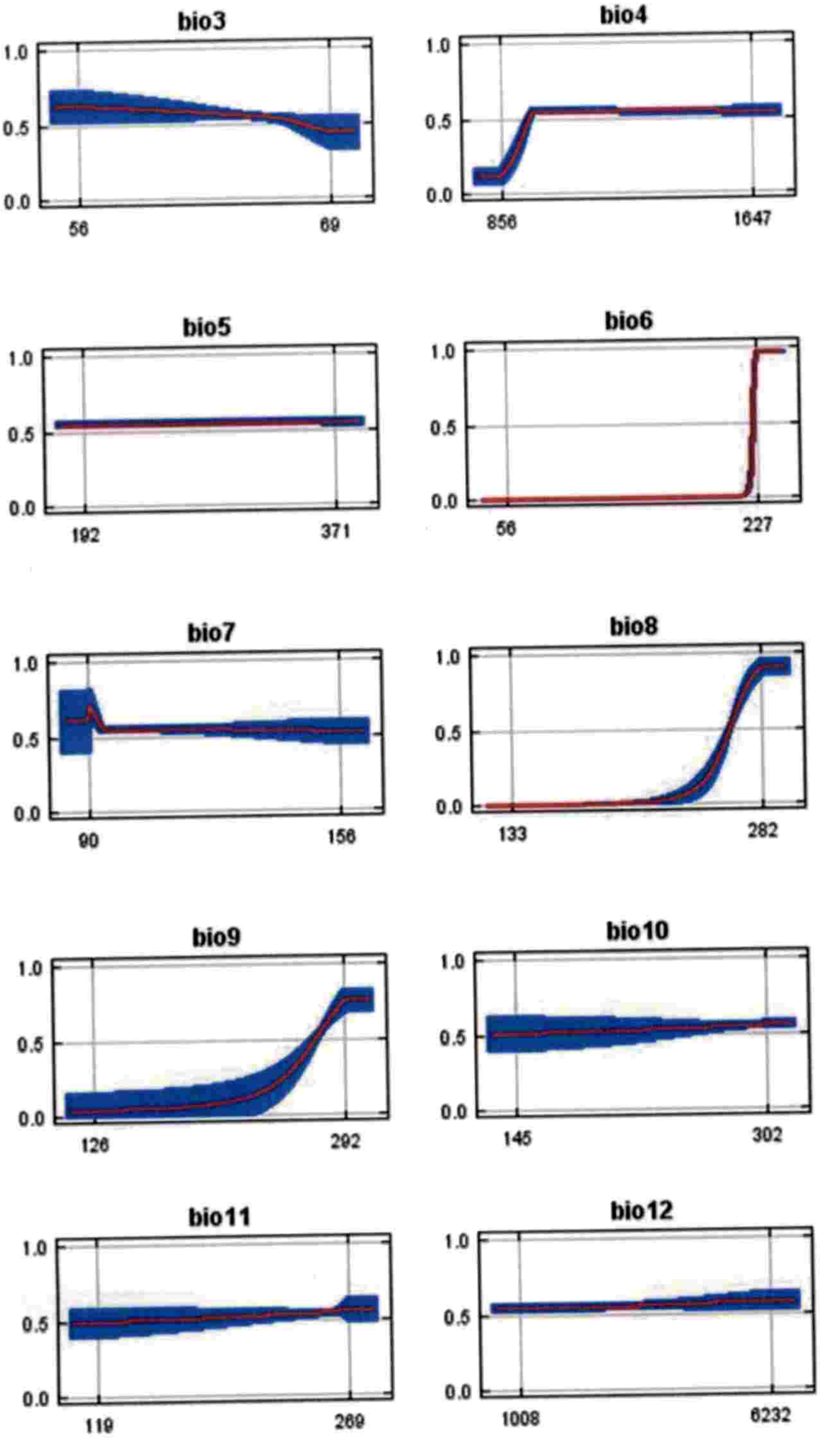
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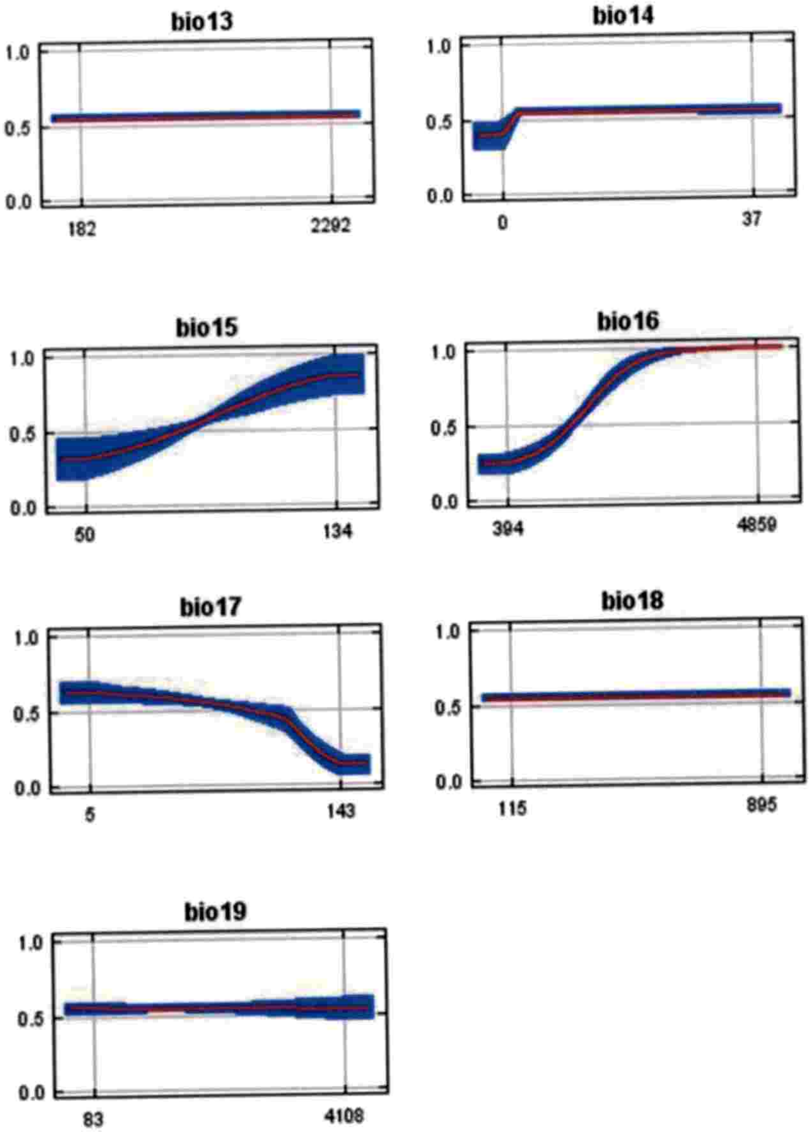
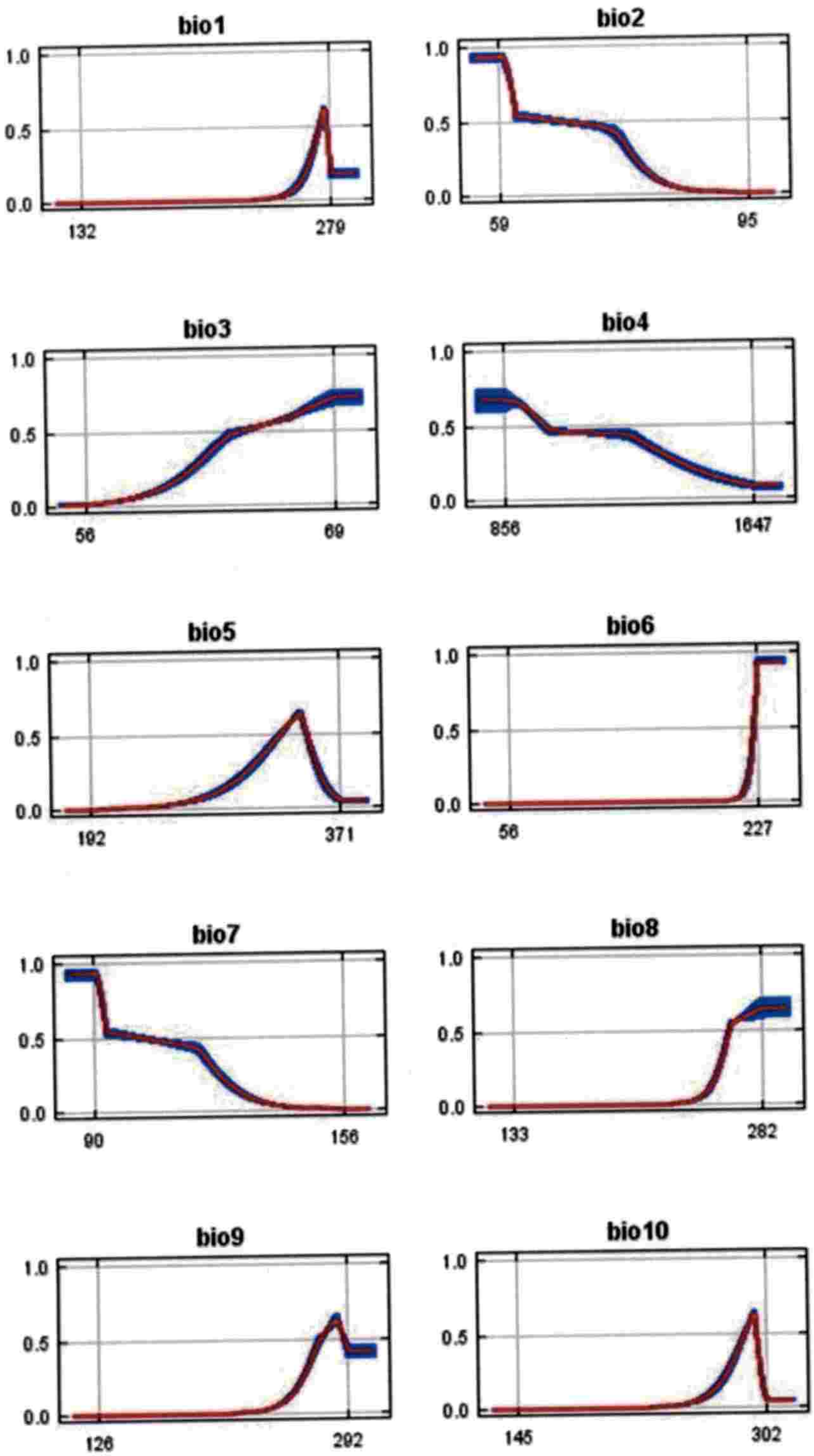


Fig.31. Response curves of each variable in the distribution of the Gray-headed Lapwing keeping all other variables at their average values


bio1
1.0
0.5
0.0
132
279
bio2
1.0
0.5
0.0
59
95
bio3
1.0
0.5
0.0
56
69
bio4
1.0
0.5
0.0
856
1647
bio5
1.0
0.5
0.0
192
371
bio6
1.0
0.5
0.0
56
227
bio7
1.0
0.5
0.0
90
156
bio8
1.0
0.5
0.0
133
282
bio9
1.0
0.5
0.0
126
292
bio10
1.0
0.5
0.0
145
302

91

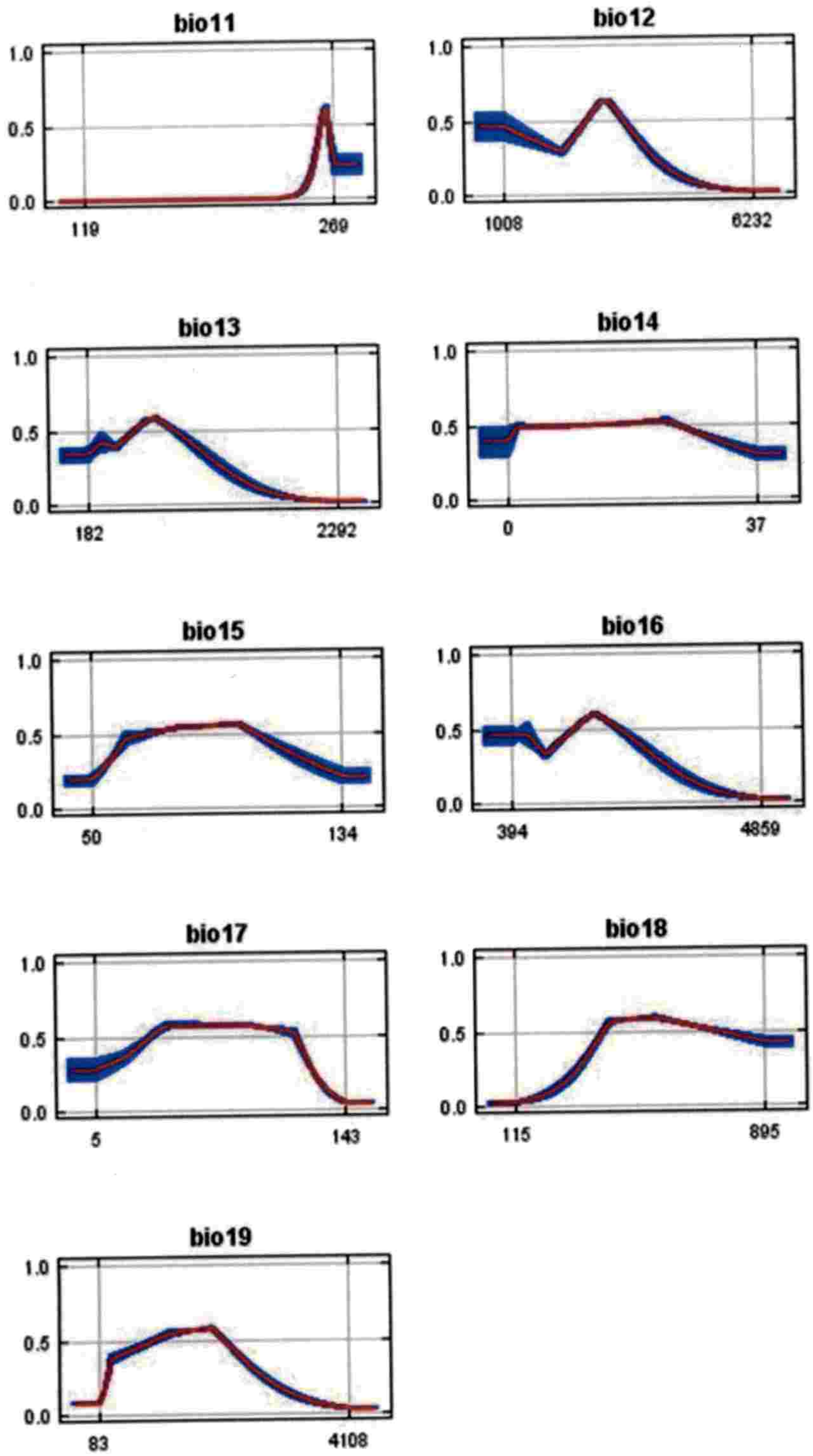


Fig.32. Response curves of each variable in determining the distribution of the Gray-headed Lapwing created using only the corresponding variable

4.3.1 VARIABLE CONTRIBUTION TO THE MODEL DISTRIBUTION OF THE GRAY-HEADED LAPWING

Table.7. Percent contribution and permutation importance of all environmental variables to the model for the Gray-headed Lapwing

Variable	Percent contribution	Permutation importance
Bio6	70	49.3
Bio9	6.8	4.9
Bio7	6.6	0.3
Bio4	4.2	1.6
Bio2	3.2	1.6
Bio17	2.9	2.6
Bio1	1.3	0.5
Bio14	1.2	0.3
Bio19	1.1	0
Bio15	0.9	5
Bio16	0.6	9.2
Bio8	0.5	24.1
Bio11	0.5	0.1
Bio3	0.2	0.5
Bio10	0	0
Bio12	0	0
Bio5	0	0
Bio13	0	0
Bio18	0	0

The percent contribution and permutation importance of all the environmental variables are given by the MaxEnt output and it is shown in Table. 7. Among the variables, the minimum temperature of the coldest month (bio6) showed high percent contribution and about 13 other variables had a percent contribution less than 10. The variables bio10, bio12, bio5, bio13, and bio18 showed no importance at all. In the case of permutation importance also bio6 showed the greatest value, next to that was bio8. Nine of the other variables showed a value less than 10.

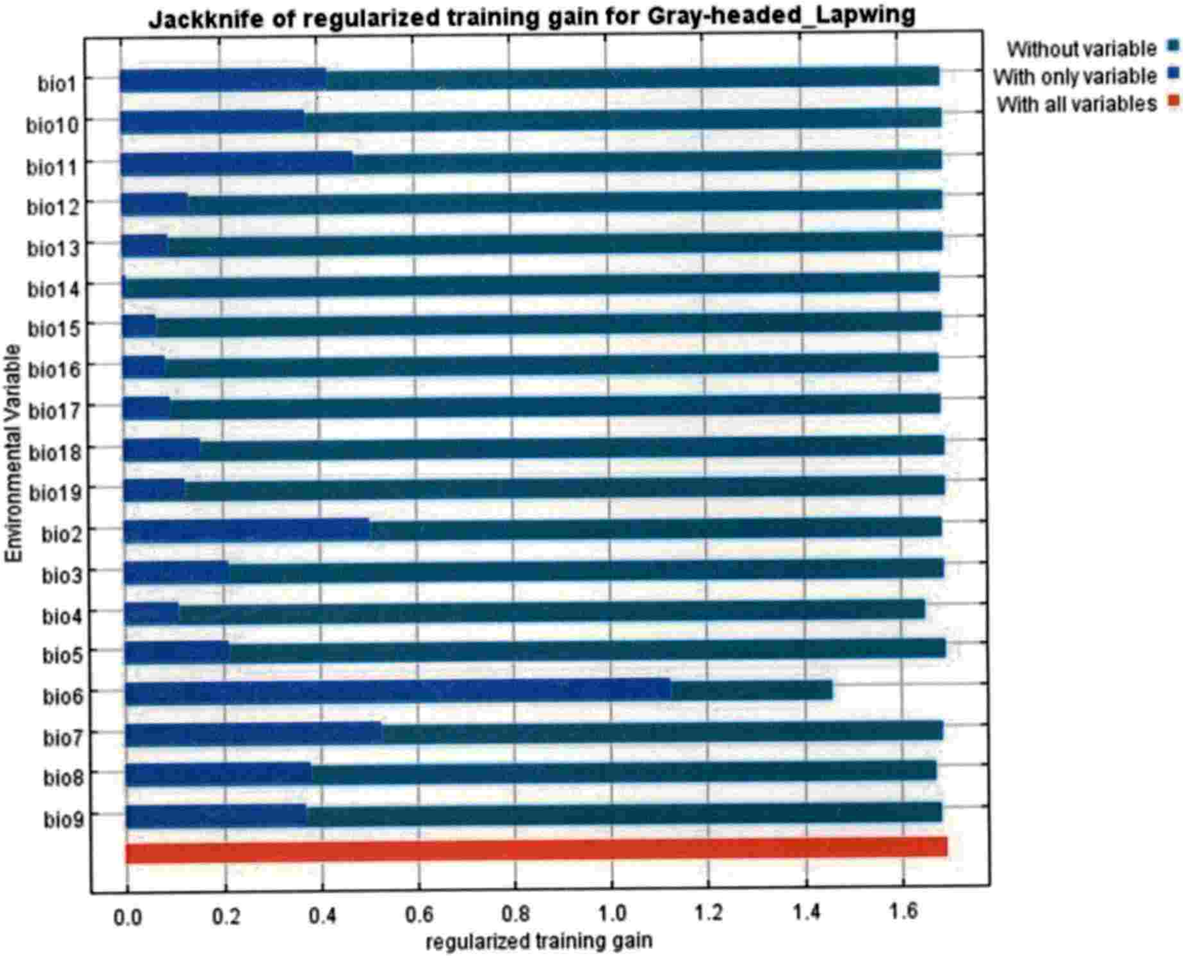


Fig.33.Jack knife analysis of regularized training gain for the Gray-headed Lapwing

The results of the jack-knife test of variable importance are shown in Fig. 33. tells that the environmental variable with highest gain when used in isolation is bio6, which therefore appears to have the most useful information by itself. The variables bio2 and bio7 lies very next to bio6 while considering the gain. The environmental variable that decreases the gain the most when it is omitted is bio6, which therefore appears to have the most information that isn't present in the other variables.

The response curves from the MaxEnt output (Fig.31) are the curves with logistic prediction as each environmental variable has varied, keeping all other environmental variables at their average sample value. Positive responses were shown higher by bio6, bio9, bio15 and bio16 compared to the moderate responses by bio1, bio4, bio5, bio7, bio10, bio11, bio12, bio13, bio14, bio18 and bio19. Some variables like bio17, bio3 and bio2 showed less significance to the survival of species.

The response curves from the MaxEnt output (Fig. 32) showed the change in predicted probability when the corresponding variable is only used. Positive responses were shown by bio3, bio6 and bio8 compared to the moderate responses by bio13, bio16, bio17 and bio 18. Variables such as bio1, bio2, bio4, bio5, bio7, bio9, bio10, bio11, bio12, bio14, bio15 and bio19 showed moderate to minimum probability.

4.3.2 Current and future predictions of the distribution of the Gray-headed Lapwing

Using the MaxEnt model and 19 environmental variables, the current distribution pattern of the Gray-headed Lapwing in Kerala was found. The presence records of the Gray-headed Lapwing were used for modelling purpose. The distribution pattern for the given bird in Kerala is depicted in Fig. 34. Mainly in the low lands of Thiruvananthapuram, with the probability of 0.85 the presence of bird was noted. There was also distribution of Gray-headed Lapwing in the low lands of Kollam and Alappuzha, the low lands and mid lands of Thrissur district with a probability greater than 50 percent.

The predicted distribution of the Gray-headed Lapwing in 2050 under the RCP 2.6 model is given in Fig. 35. It was observed that the distribution of the Gray-headed Lapwing would strongly expand to the mid lands of Thiruvananthapuram, low lands of Kollam, low, mid and high lands of Ernakulam, lowlands and mid lands of Thrissur, mid lands of Palakkad, midlands and high lands of Malappuram, then to the low lands and mid lands of Kozhikode, Kannur and Kasargode There is also a less stronger probability of expansion of bird distribution to the mid lands of Palakkad, mid lands of Pathanamthitta, mid lands of Kollam, mid and high lands of Kottayam, low lands of Alappuzha, low lands of Thiruvananthapuram.

The predicted distribution of the Gray-headed Lapwing in 2050 under the RCP 4.5 model is given in Fig.36. It was observed that the distribution of the Gray-headed Lapwing would expand to the low, mid and high lands of Thiruvananthapuram, low and mid lands of Kollam, low lands of Alappuzha, mid and high lands of Pathanamthitta, mid and high lands of Kottayam, low, mid and high lands of Ernakulam, low and mid lands of Kozhikode, Kannur, Kasargode, low, mid and high lands of Thrissur, low and midlands of Malappuram, low and mid lands of Ernakulam, mid and high lands of Palakkad.

The predicted distribution of the Gray-headed Lapwing in 2050 under the RCP 6.0 model is given in Fig. 37.A strong southward expansion of the Gray-headed Lapwing was seen under the RCP6.0 model predictions to the low lands and some regions of mid lands of Thiruvananthapuram, low lands of Kollam and Alappuzha, low lands and midlands of Pathanamthitta and Kottayam, the lowlands of Kasargode, lowlands and midlands of Kannur, Kozhikode, lowlands, mid lands and high lands of Malappuram and Thrissur, low and mid lands of Ernakulam.

The predicted distribution of the Gray-headed Lapwing in 2050 under the RCP 8.5 model is given in Fig. 38. According to RCP 8.5 model, the abundance of distribution of the Gray-headed Lapwing would be higher in the low lands, mid lands and high lands of Kannur, Kasargode and Kozhikode, low lands, mid lands and high lands of Thiruvananthapuram, low lands and mid lands of Ernakulam, low lands and mid lands of Thrissur, low, mid and high lands of Malappuram. The expansion is less strong in the low and mid lands of Kollam, mid lands of Pathanamthitta, some regions of low lands of Alappuzha.

The predicted distribution of the Gray-headed Lapwing in 2070 under the RCP 2.6 model is given in Fig. 39. The model shows that the north and south tip of Kerala would be rich in distribution of the Gray-headed Lapwing in the future. Some regions of mid lands of Kannur and Kasargode, high lands of Malappuram and Palakkad, mid lands of Thiruvananthapuram and Kollam, high lands of Pathanamthitta would be probable to the distribution of Gray-headed Lapwing at lesser strength.

The predicted distribution of the Gray-headed Lapwing in 2070 under the RCP 4.5 model is given in Fig. 40.According to the model, the abundance of distribution of the Gray-headed Lapwing would be greater in the low, mid and some parts of high lands of Thiruvananthapuram, low and mid lands of Kollam, mid lands of Pathanamthitta, high lands of Kottayam, low lands of Alappuzha, low, mid and high lands of Thrissur, low and mid lands of Ernakulam, low lands, mid lands and some parts of high lands of Malappuram, low and mid lands of Kannur Kozhikode and Kasargode.

The predicted distribution of the Gray-headed Lapwing in 2070 under the RCP 6.0 model is given in Fig. 41. It is same as that of the 2070 RCP 4.5 model. The distribution of the Gray-headed Lapwing would be strongly expanding to the low lands, mid lands and some parts of high lands of Thiruvananthapuram, low and mid lands of Kollam, mid lands of Pathanamthitta, high lands of Kottayam, low lands of Alappuzha, low lands, mid lands and high lands of Thrissur, low lands and mid lands of Ernakulam, low lands, mid lands and some parts of high lands of Malappuram, low lands and mid lands of Kannur, Kozhikode and Kasargode.

The predicted distribution of the Gray-headed Lapwing in 2070 under the RCP 8.5 model is given in Fig. 42. According to the model, the distribution of Gray-headed Lapwing will be richer in the low lands, mid lands and high lands of Thiruvananthapuram, low lands, mid lands, and high lands of Kollam, mid lands of Pathanamthitta, low lands of Alappuzha, some parts of high lands of Idukki, low lands, mid lands and high lands of Ernakulam, mid and high lands of Kottayam, lowlands, mid lands and some parts of high lands of Malappuram, low lands and mid lands of Kozhikode, Kannur and Kasargode.

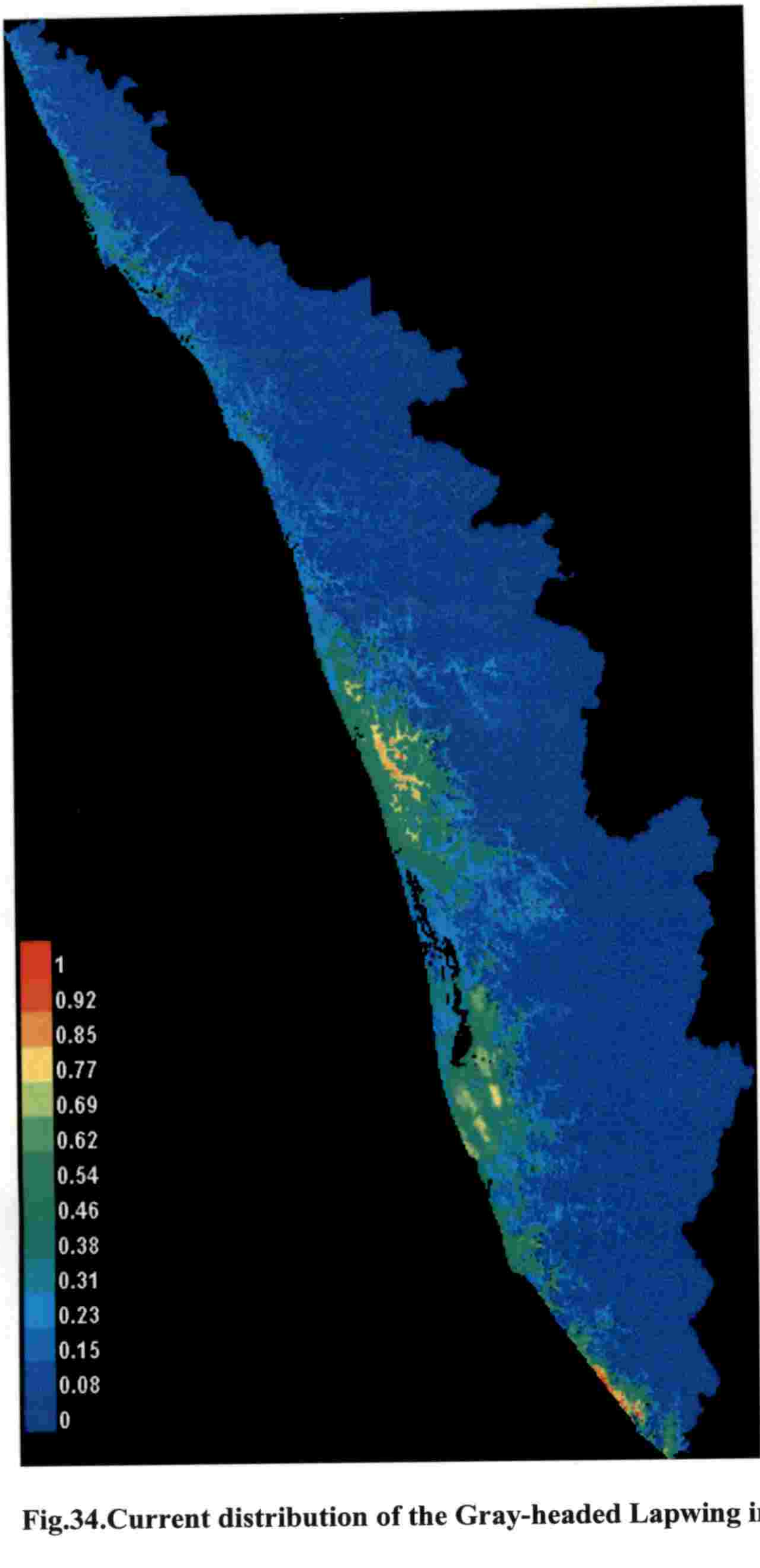


Fig.34.Current distribution of the Gray-headed Lapwing in Kerala

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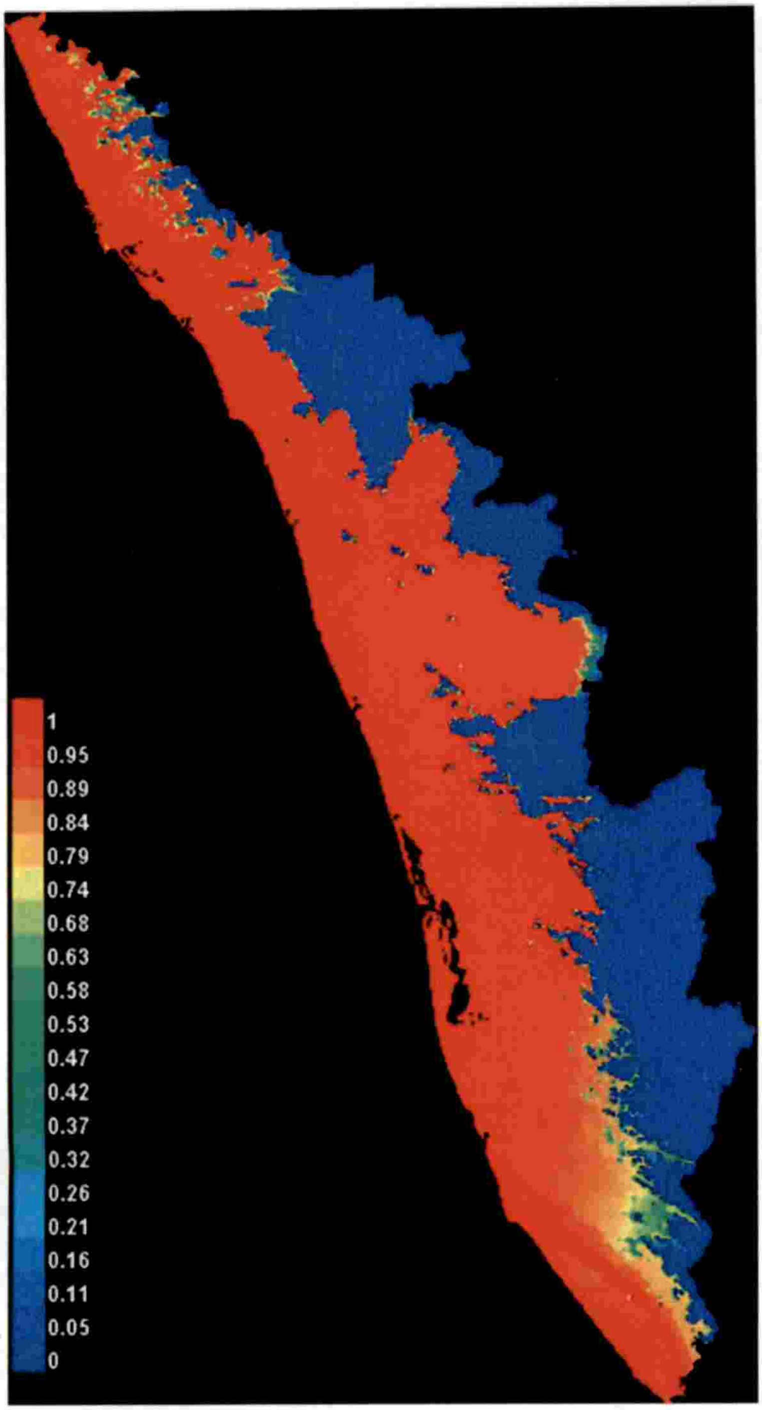

Fig. 35. Prediction of the future distribution of the Gray-headed Lapwing for 2050 under RCP2.6 prediction

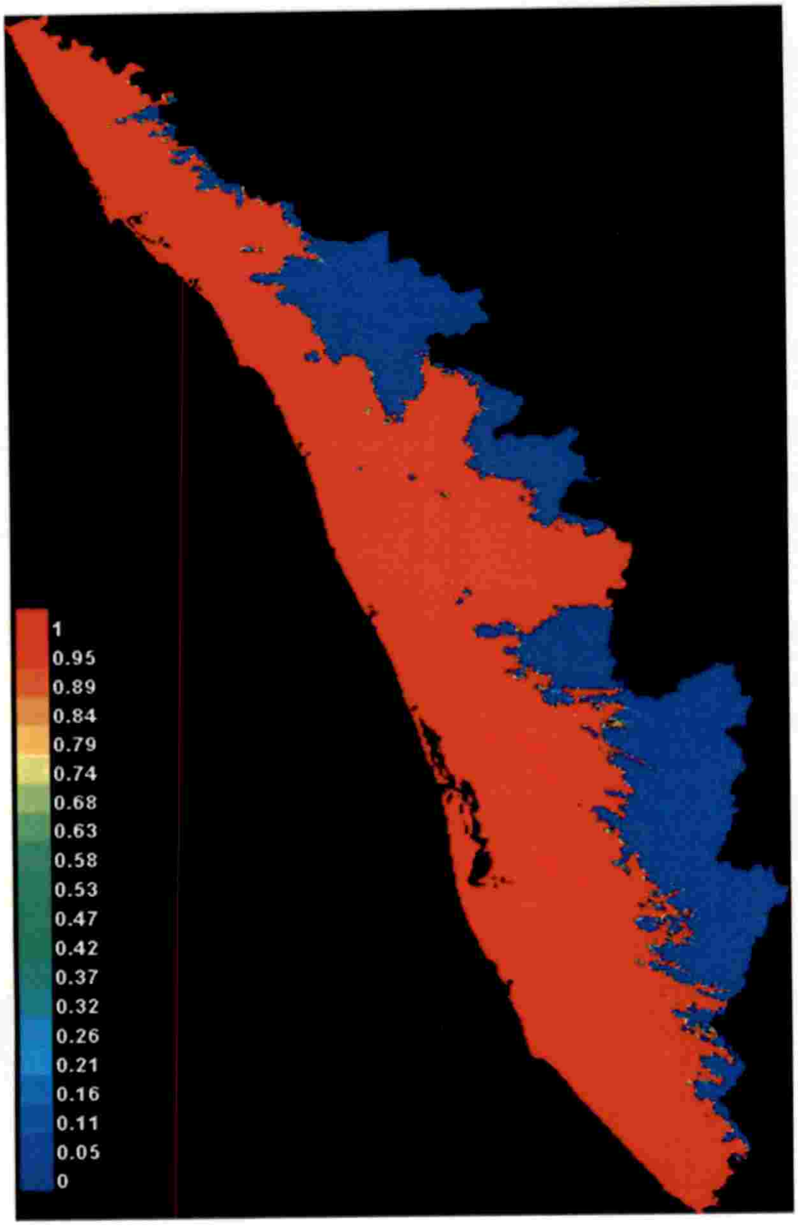

Fig. 36.Prediction of the future distribution of the Gray-headed Lapwing for 2050 under RCP4.5 prediction

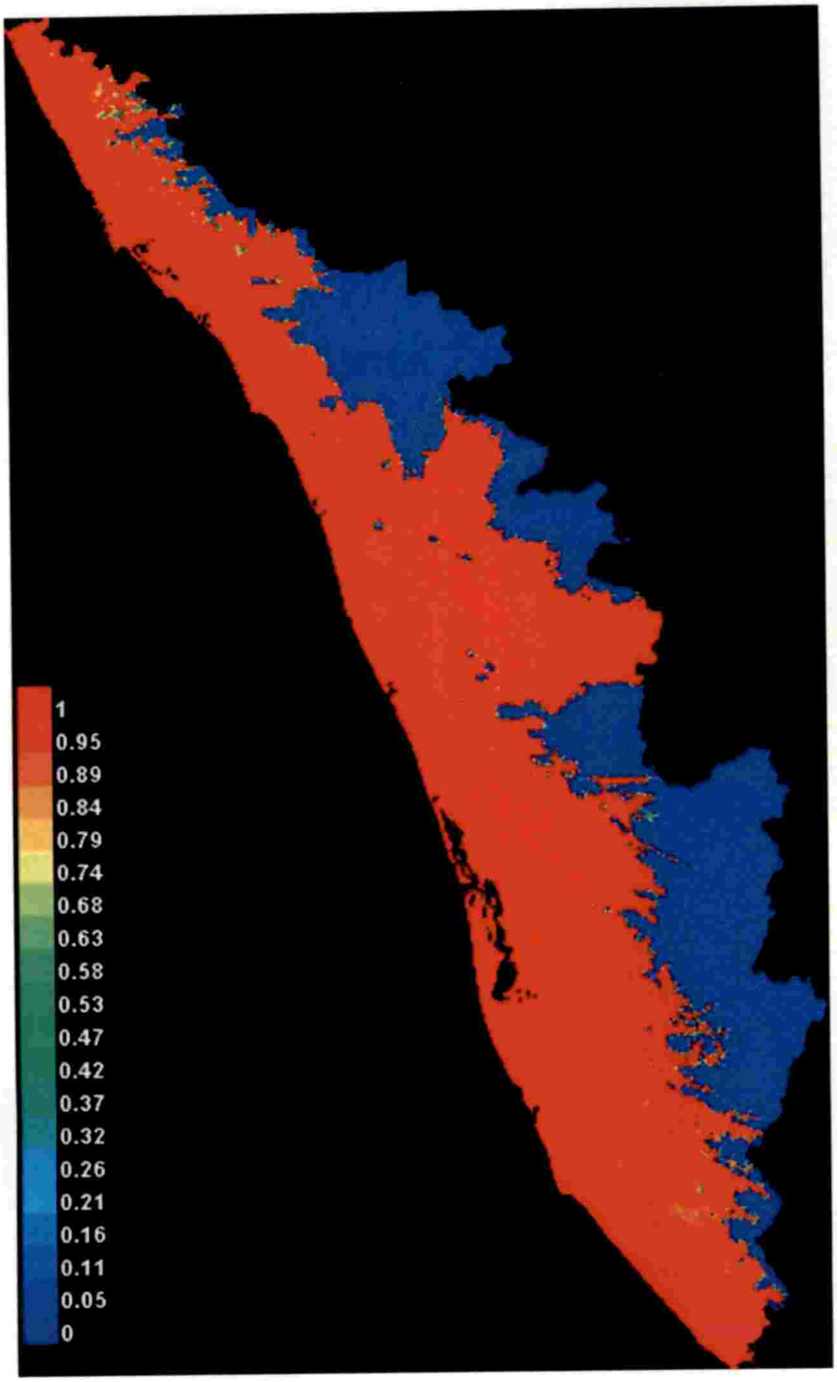

Fig. 37. Prediction of the future distribution of the Gray-headed Lapwing for 2050 under RCP6.0 prediction

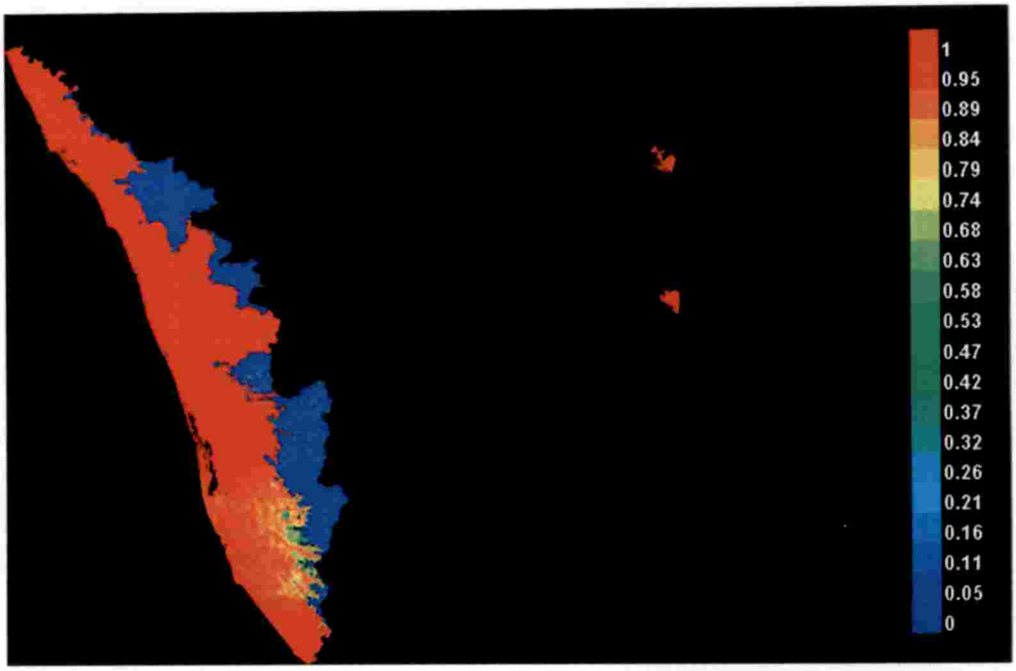

Fig. 38.Prediction of the future distribution of the Gray-headed Lapwing for 2050 under RCP8.5 prediction

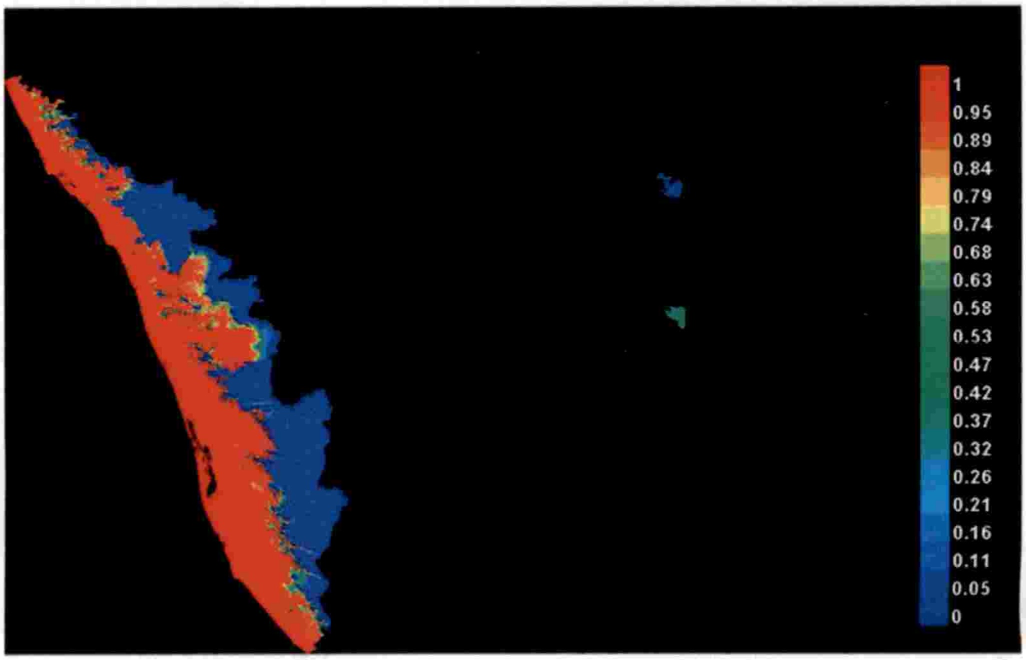

Fig. 39. Prediction of the future distribution of theGray-headed Lapwing for 2070 under RCP2.6 prediction

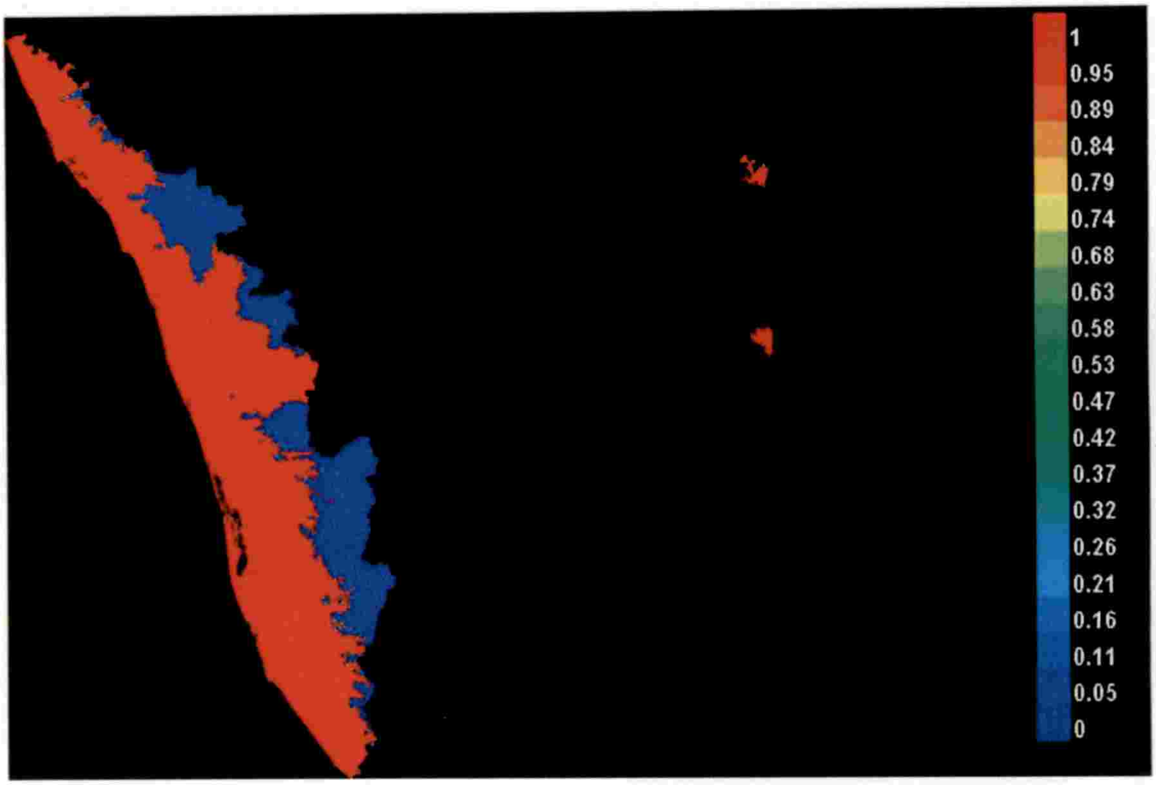

Fig. 40. Prediction of the future distribution of the Gray-headed Lapwing for 2070 under RCP4.5 prediction

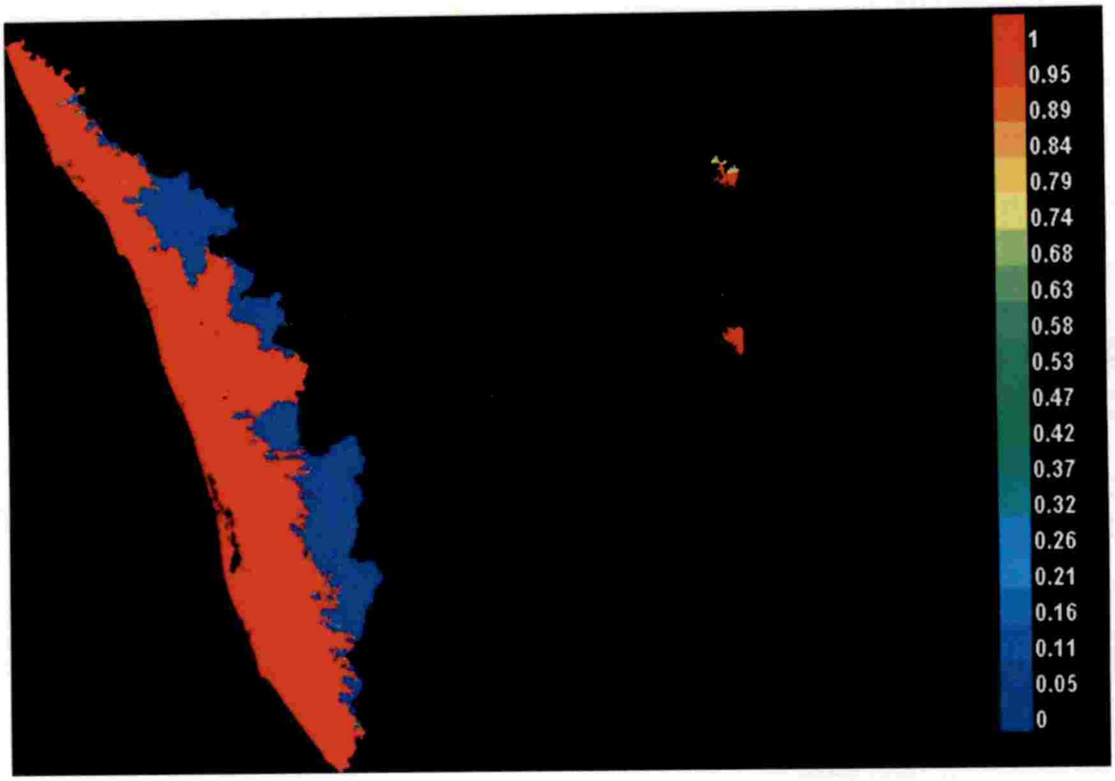

Fig. 41. Prediction of the future distribution of the Gray-headed Lapwing for 2070 under RCP6.0 prediction

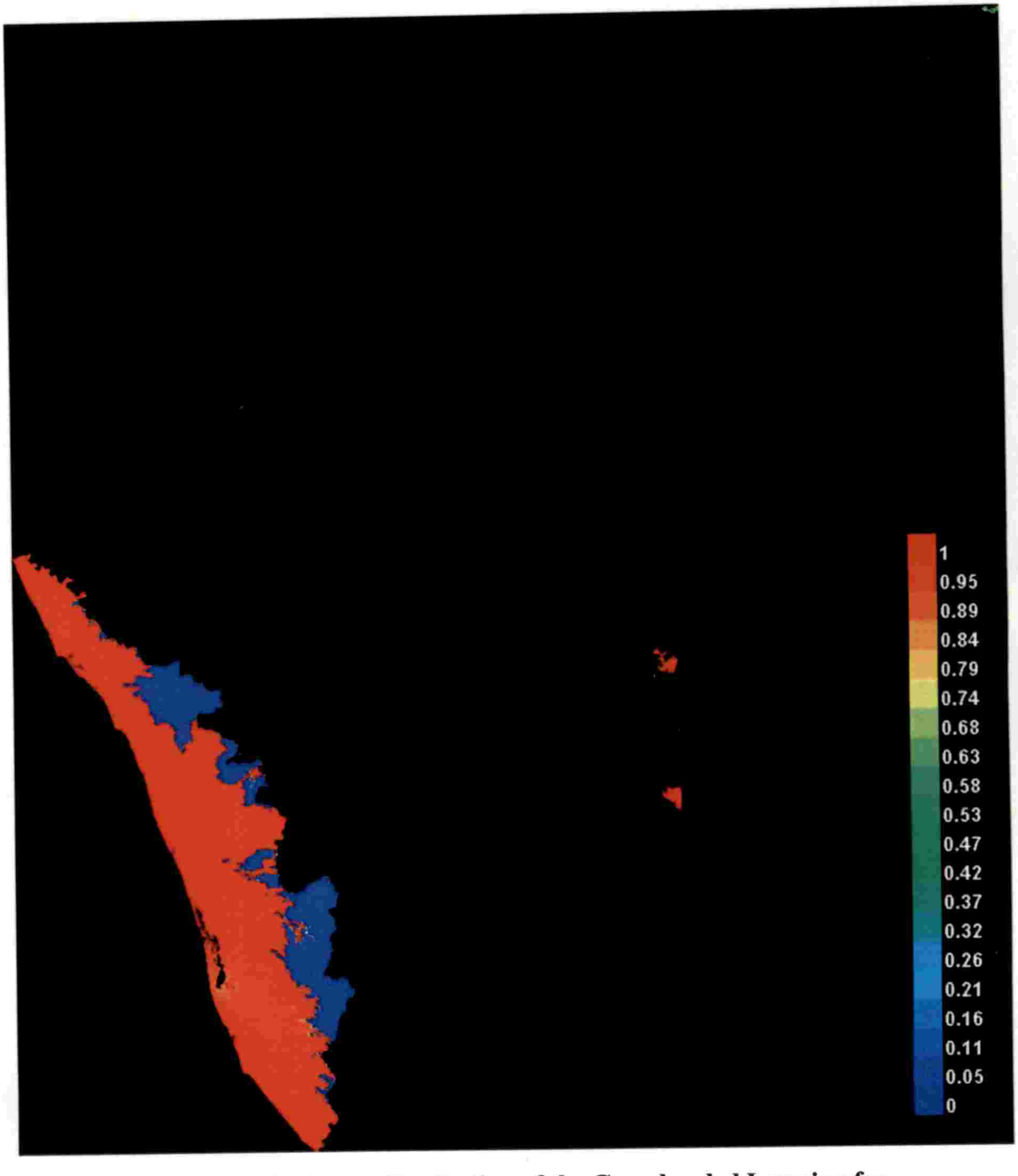

Fig. 42. Prediction of the future distribution of the Gray-headed Lapwing for 2070 under RCP8.5prediction

4.4 STONECHAT

To select the better model for accurate results, 4 different models were run by MaxEnt and the corresponding AUC values and SD were analysed for the given bird.

Table. 8. Average test AUC values and SD of each model of the distribution of the Stonechat

Model trial no.	AUC values	SD
1	0.865	0.080
2	0.871	0.056
3	0.860	0.061
4	0.865	0.049

Sincethe second model has the best AUC value and lower SD so it was selected as the better one for further species distribution modelling.

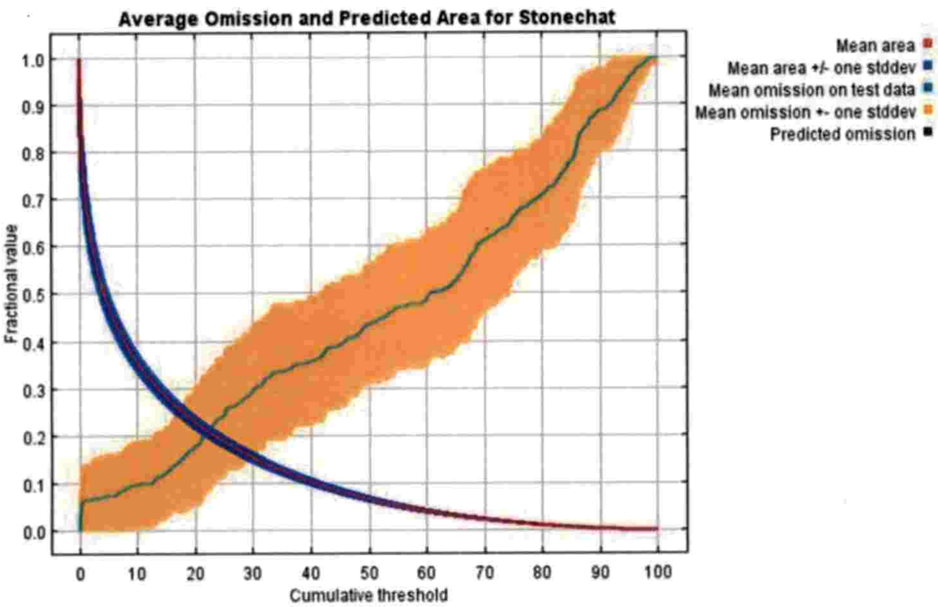

Figure. 43. shows the Test omission rate and predicted area as a function of the cumulative threshold, averaged over the replicate runs for the Stonechat

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Here the mean omission line is almost passing through the predicted omission line and the result is good for the model.

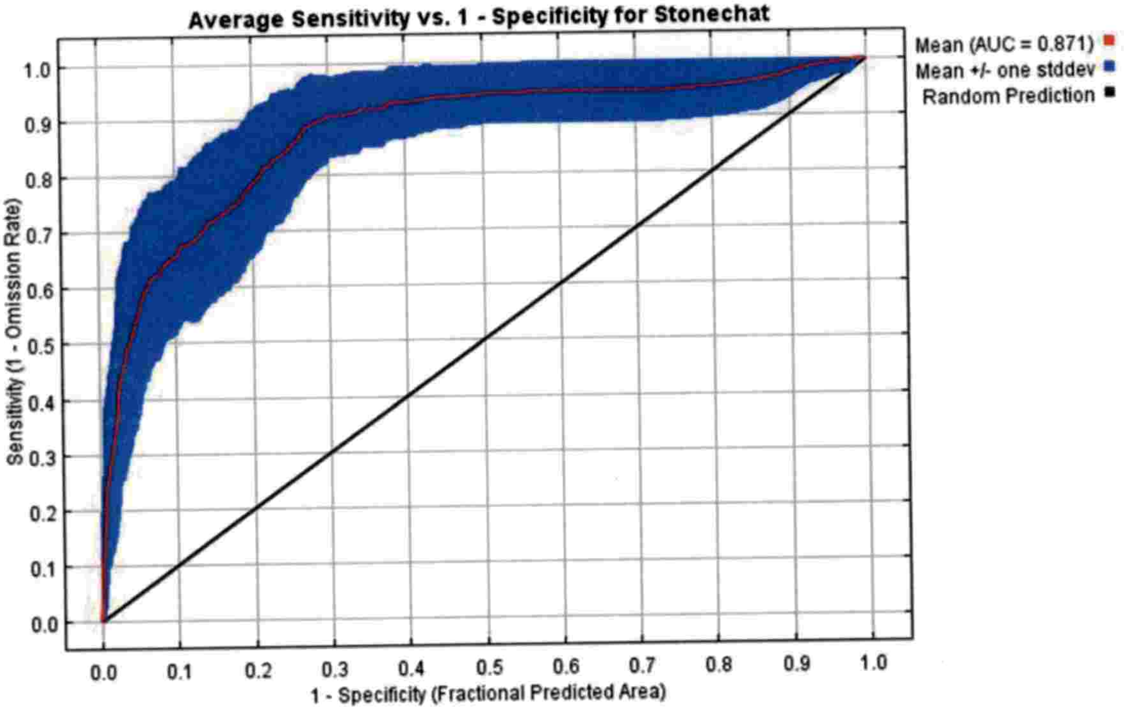
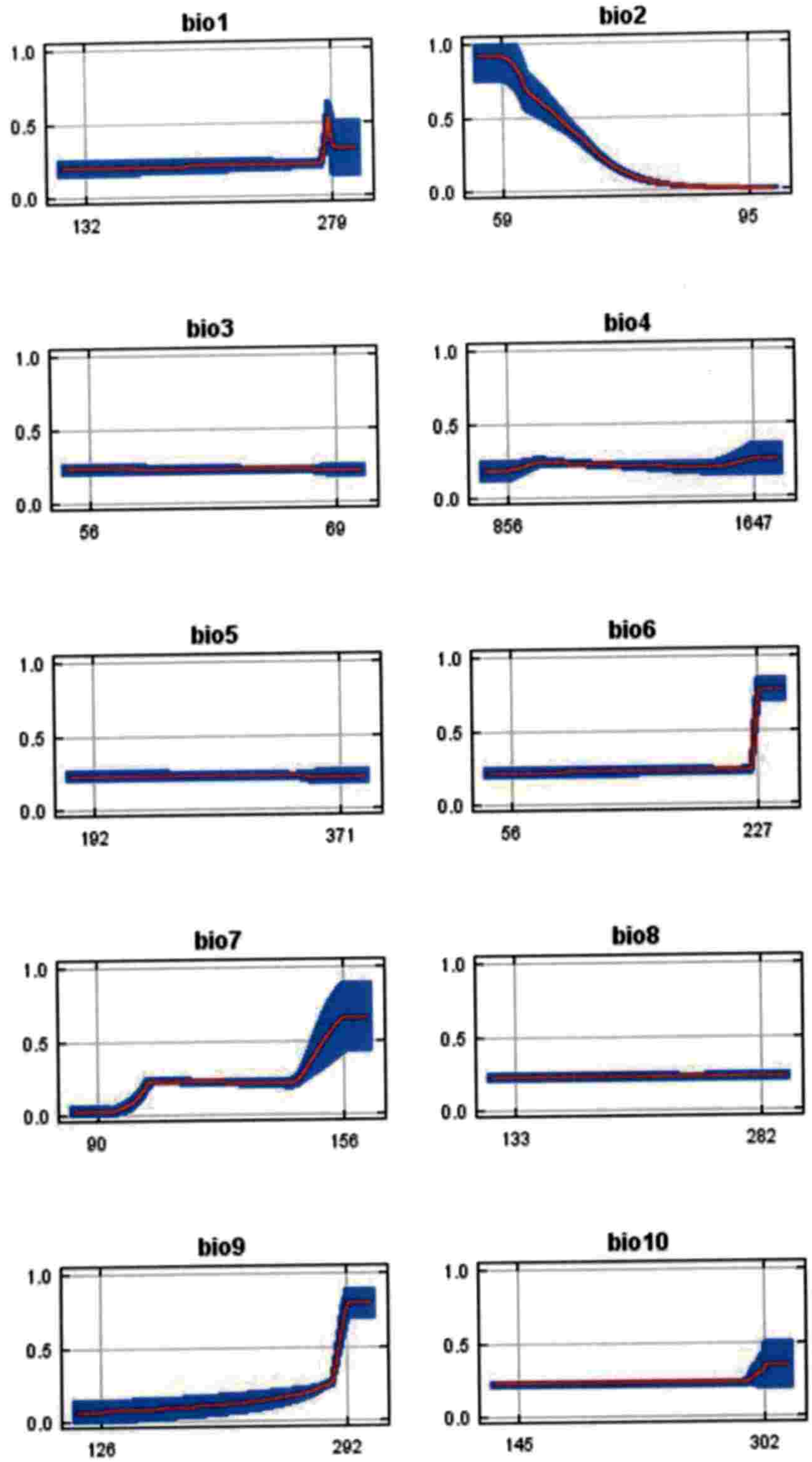


Fig.44. depicts the ROC curve averaged over the replicated runs of the given model for the Stonechat

The ROC curve passed above the random prediction line and positioned towards the left top of the graph.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1.0
0.5
0.0
132
279
bio2
1.0
0.5
0.0
59
95
bio3
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0.5
0.0
56
69
bio4
1.0
0.5
0.0
856
1647
bio5
1.0
0.5
0.0
192
371
bio6
1.0
0.5
0.0
56
227
bio7
1.0
0.5
0.0
90
156
bio8
1.0
0.5
0.0
133
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bio9
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0.0
126
292
bio10
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0.0
145
302

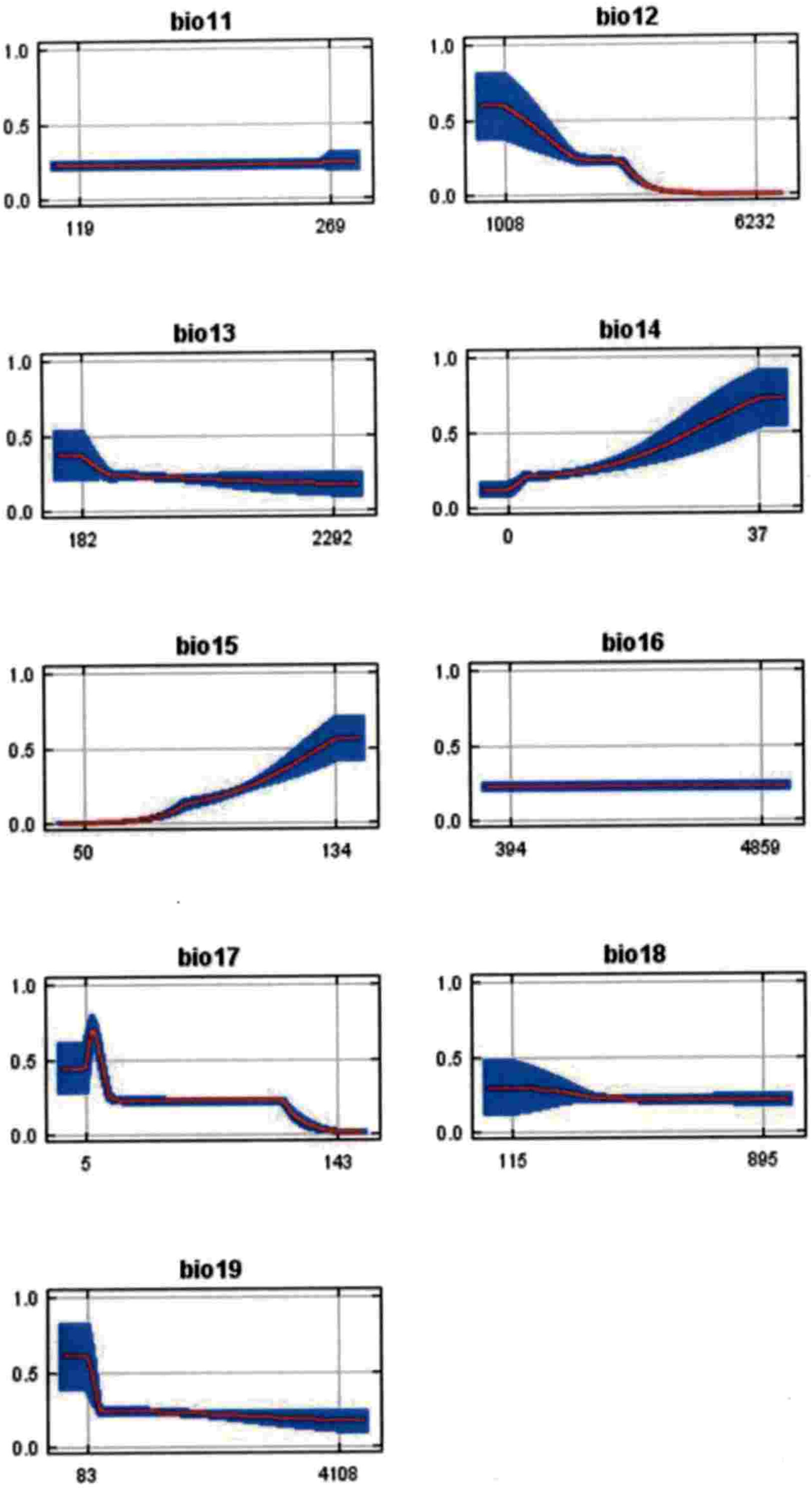
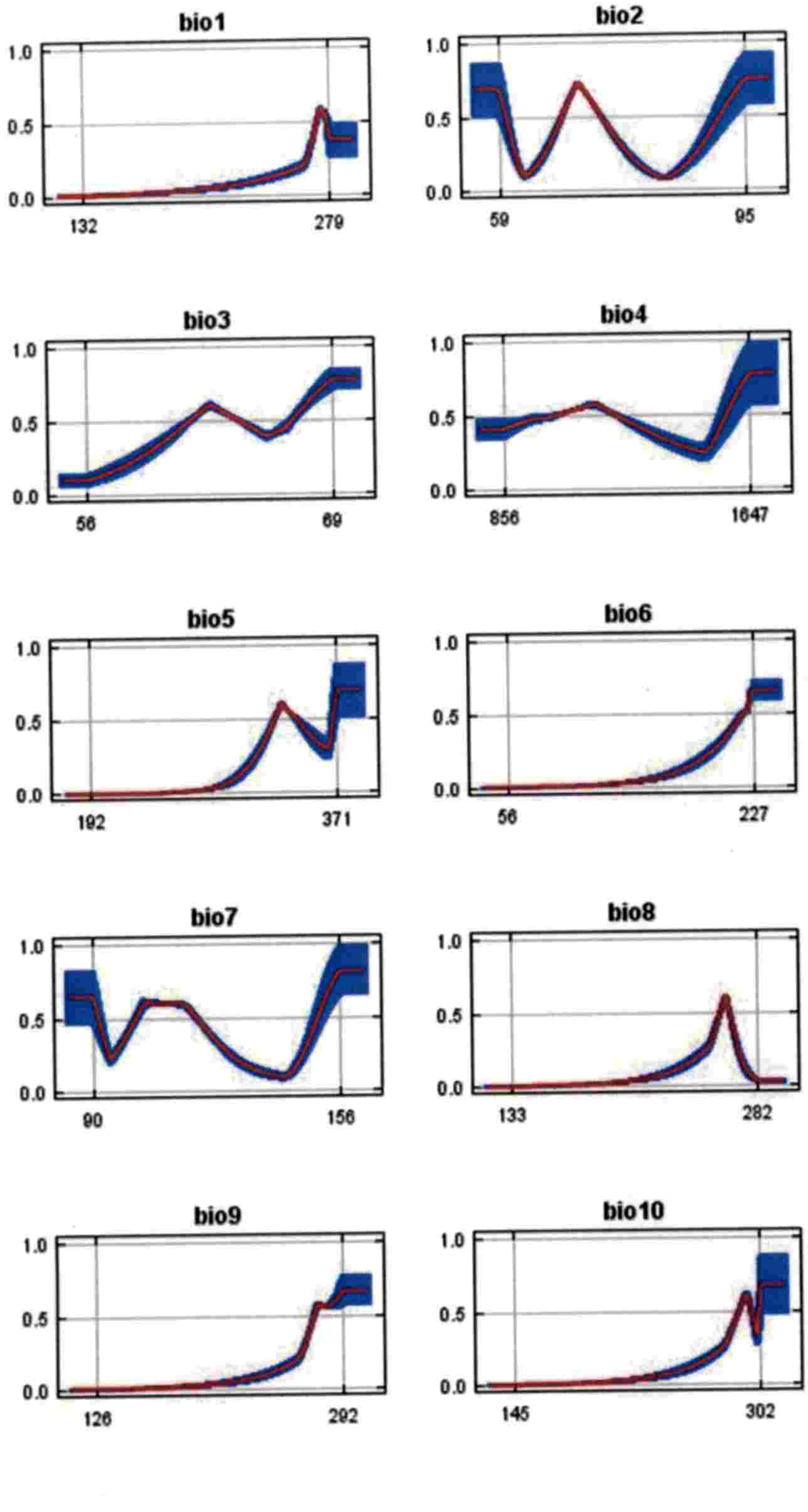


Fig. 45. Response curves of each variable in the distribution of the Stonechat keeping all other variables at their average values


bio1
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bio2
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bio3
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bio4
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1647
bio5
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bio6
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bio7
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bio8
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bio10
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302

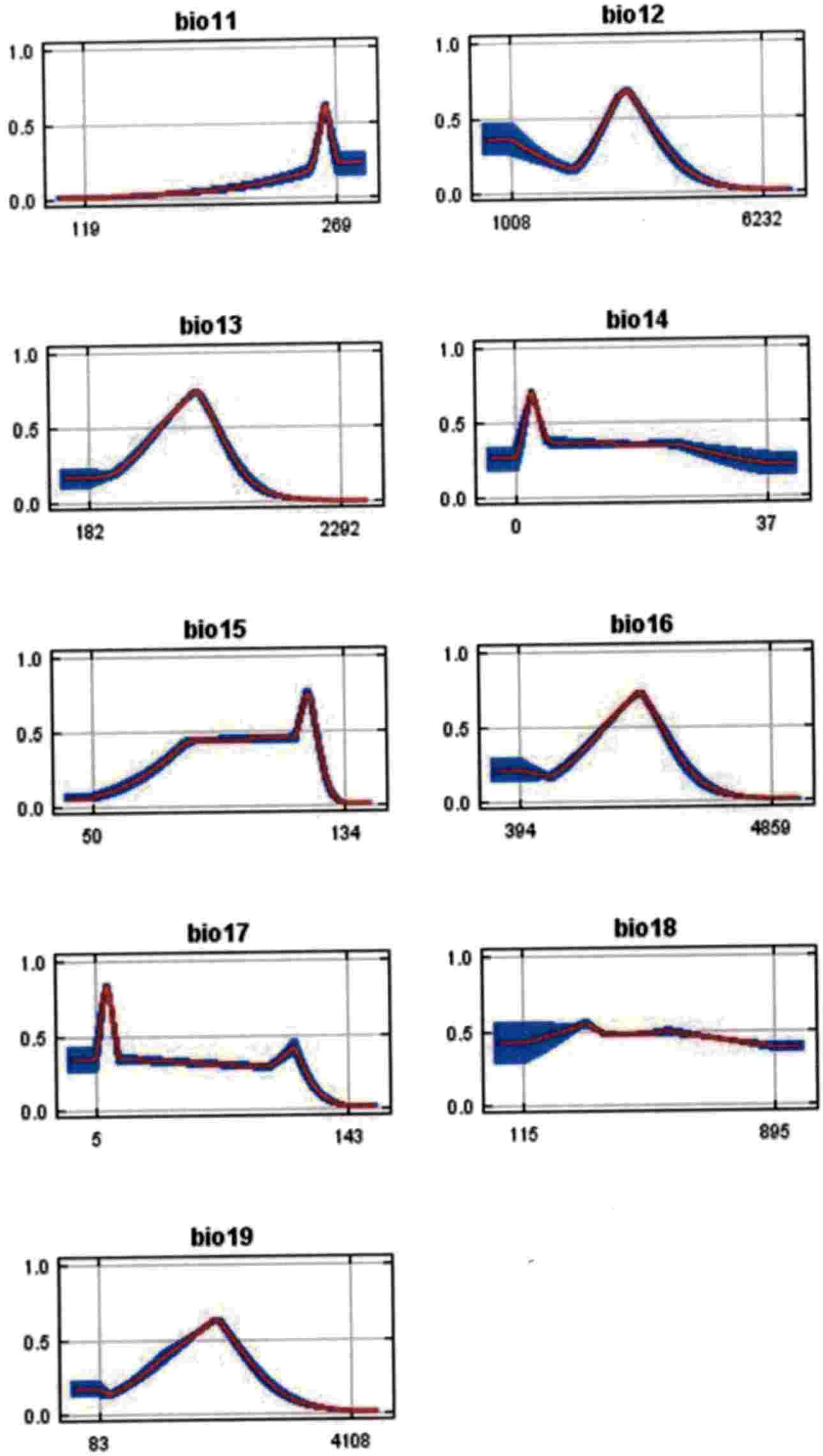

Fig. 46.Response curves of each variable in determining the distribution of the Stonechat created using only the corresponding variable

4.4.1 VARIABLE CONTRIBUTION TO THE MODEL DISTRIBUTION OF THE STONECHAT

Table. 9. Percent contribution and permutation importance of all variables to the model for the Stonechat

Variable	Percent contribution	Permutation importance
Bio17	30.5	10.2
Bio6	21	4.7
Bio19	17.8	2.5
Bio12	6.4	11.6
Bio9	5.8	5.5
Bio2	5.6	20.7
Bio14	3.6	5.3
Bio7	3.2	8.3
Bio15	2.2	24.3
Bio1	1.7	4
Bio4	1.1	0.4
Bio10	0.3	0.5
Bio13	0.3	0.9
Bio5	0.2	0.5
Bio11	0.1	0.1
Bio18	0.1	0.4
Bio3	0	0
Bio16	0	0
Bio8	0	0

The percent contribution and permutation importance of all the environmental variables are given by the MaxEnt output and it is shown in Table. 9. Among the variables, the precipitation of the driest quarter (bio17) showed high percent contribution of about 30.5 followed by bio6 and bio19 with percent values of 21 and 17.8 respectively. Remaining variables had a percent contribution only less than 10. The variables bio3, bio16 and bio8 showed no importance at all. In the case of permutation importance bio15 showed the greatest value, next to that was bio2 with a value of 20.7. Other than bio12 (11.6) and bio17 (10.2), the remaining variables showed less importance to species' existence. Nine of the other variables showed a value less than 10.

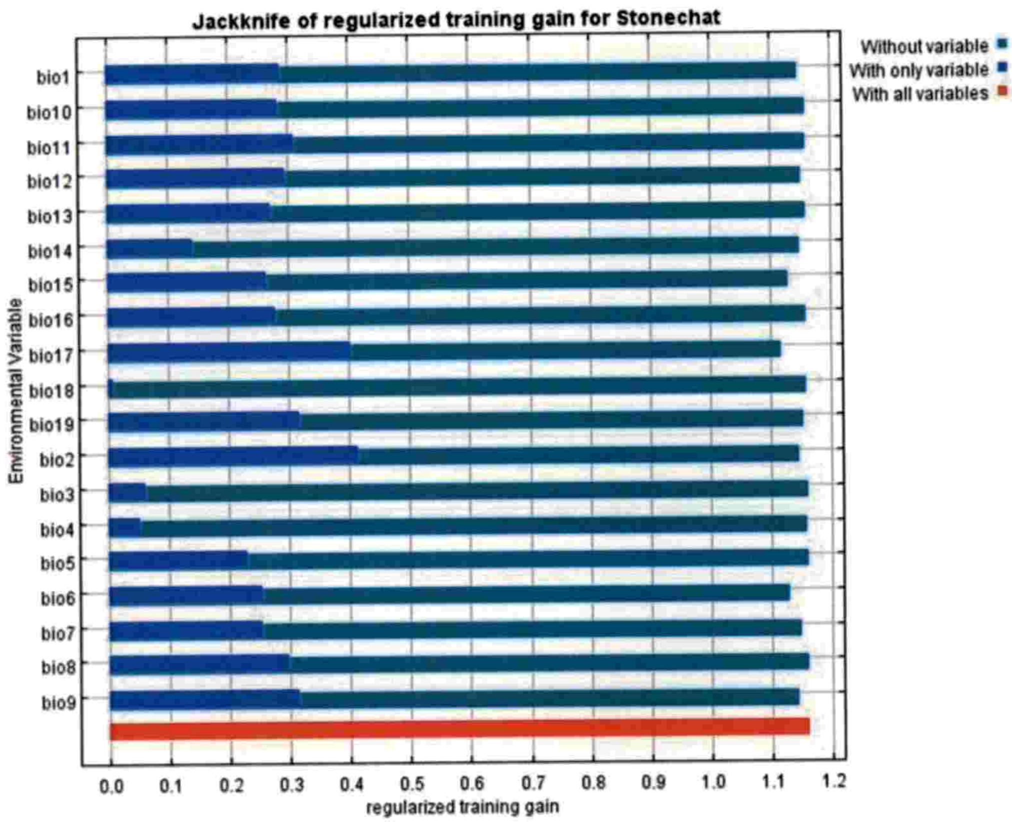

Fig. 47.Jackknife analysis of regularized training gain for the Stonechat using all the variables

The results of the jackknife test of variable importance shown in Fig. 47. Tell that the environmental variable with highest gain when used in isolation is bio2,

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which therefore appears to have the most useful information by itself followed by bio17. The environmental variable that decreases the gain the most when it is omitted is bio17, which therefore appears to have the most information that isn't present in the other variables.

The response curves from the MaxEnt output Fig. 45. are the curves with logistic prediction changes as each environmental variable has varied, keeping all other environmental variables at their average sample value. Positive responses were shown by bio6, bio7, bio9, bio14 and bio15. The variables bio1, bio2, bio12, bio17 and bio19 showed moderate response to species distribution. Below 50 percent probability was observed for the remaining variables with regard to the distribution of birds.

The response curves from the MaxEnt output Fig. 46. showed the change in predicted probability when the corresponding variable is only used. Positive responses were shown by bio2, bio3, bio4, bio5, bio6, bio7, bio9 and bio10. At the same time all the remaining variables showed moderate to low responses.

4.4.2 Current and future predictions of the distribution of the Stonechat

The current distribution pattern depicted in Fig. 48. showed the abundance of the Stonechat in the low lands of Kannur. Also the presence was observed on some parts of mid lands of Thrissur, low lands and mid lands of Alappuzha. There were presences of the Stonechat in the low lands of Thiruvananthapuram and high lands of Palakkad near the Palakkad gap.

The predicted distribution of the Stonechat in 2050 under the RCP 2.6model is given in Fig. 49. There would be a stronger distribution of the Stonechat in the low lands of Kasargode and Kannur, low lands and mid lands of Kozhikode, low lands, mid lands and high lands of Malappuram. Also the distribution would be increasing to the high lands of Palakkad, low lands and mid lands of Thrissur, low lands of Ernakulam, mid lands and high lands of Thiruvananthapuram. The bird distribution would be spreading to some parts of the mid lands of Thrissur and Palakkad, mid lands of Alappuzha and Kottayam and low lands of Kollam.

The predicted distribution of the Stonechat in 2050 under the RCP4.5 model is given in Fig. 50. The occurrence of the Stonechat would be greater towards the entire plains of Kerala and also in some parts of the high lands of Wayanad. The bird distribution would spread to low lands, mid lands and high lands of the entire districts of Kerala excluding the high lands of Idukki, some parts of high lands of Palakkad and Thrissur and major portion of high lands of Wayanad.

The predicted distribution of the Stonechat in 2050 under the RCP6.0 model is given in Fig. 51. There would be extremely stronger abundance of the Stonechat in the low lands, mid lands and high lands of Thiruvananthapuram, Kasargode, Kannur and Kozhikode, low lands, mid lands and high lands of Malappuram, low lands and mid lands of Thrissur, low lands, mid lands and high lands of Ernakulam, mid lands and high lands of Kottayam, low lands of Alappuzha and Kollam, mid lands and some parts of high lands of Palakkad.

The predicted distribution of the Stonechat in 2050 under the RCP8.5 model is given in Fig. 52. According to the model, the abundance of distribution of the Stonechat would be stronger along the entire plains of Kerala state excepting the high lands of Wayanad and Idukki, some parts of high lands of Palakkad and Thrissur. The result obtained was similar to that of the 2050 RCP2.6 model.

The predicted distribution of Stonechat in 2070 under the RCP 2.6 model is depicted in Fig. 53. The presence of the Stonechat would be expanding at a stronger rate to the lowlands of Kasargode and Kannur. There would be a greater presence of the bird towards the low lands and mid lands of Malappuram, some parts of mid lands and some regions of high lands of Palakkad, low lands, midlands and high lands of Thiruvananthapuram, low lands of Alappuzha, mid lands of Kottayam and Pathanamthitta.

The predicted distribution of the Stonechat in 2070 under the RCP 4.5 model is depicted in Fig. 54. The distribution of Stonechat would be expected to increase to the entire district of Thiruvananthapuram, some of the low land areas of Kollam, some regions of low lands, mid lands and high lands of Ernakulam, low lands, mid lands and high lands of Thrissur, mid lands and some areas of high lands of Palakkad, low lands, mid lands and high lands of Malappuram, low lands and mid lands of Kozhikode, low lands, mid lands and some areas of high lands of Kannur, low lands, mid lands and high lands of Kasargode.

The predicted distribution of the Stonechat in 2070 under the RCP 6.0 model is given in Fig. 55. There would be greater distribution of the bird towards the low lands, mid lands and high lands of Thiruvananthapuram, low lands, mid lands and some areas of high lands of Kollam, low lands and mid lands of Alappuzha, midlands and high lands of Pathanamthitta, midlands and high lands of Kottayam, low lands, mid lands and high lands of Ernakulam and Thrissur, mid lands and some parts of high lands of Palakkad, low lands, mid lands and high lands of Malappuram, low lands and mid lands of Kozhikode, low lands and mid lands of Kannur and low lands, mid lands and some areas of high lands of Kasargode.

The predicted distribution of the Stonechat in 2070 under the RCP 8.5 model is depicted in Fig. 56. According to the model the bird distribution would spread strongly to the low lands, mid lands and major parts of high lands of Thiruvananthapuram, low lands, mid lands and high lands of Kollam and low lands and mid lands of Alappuzha, midlands and high lands of Pathanamthitta, some regions of high lands of Idukki, midlands and high lands of Kottayam, low lands, mid lands and high lands of Ernakulam and Thrissur, mid lands and some major areas of high lands of Palakkad, low lands and mid lands of Kozhikode and Kannur, low lands, mid lands and high lands of Kasargode, low lands, mid lands and high lands of Malappuram.

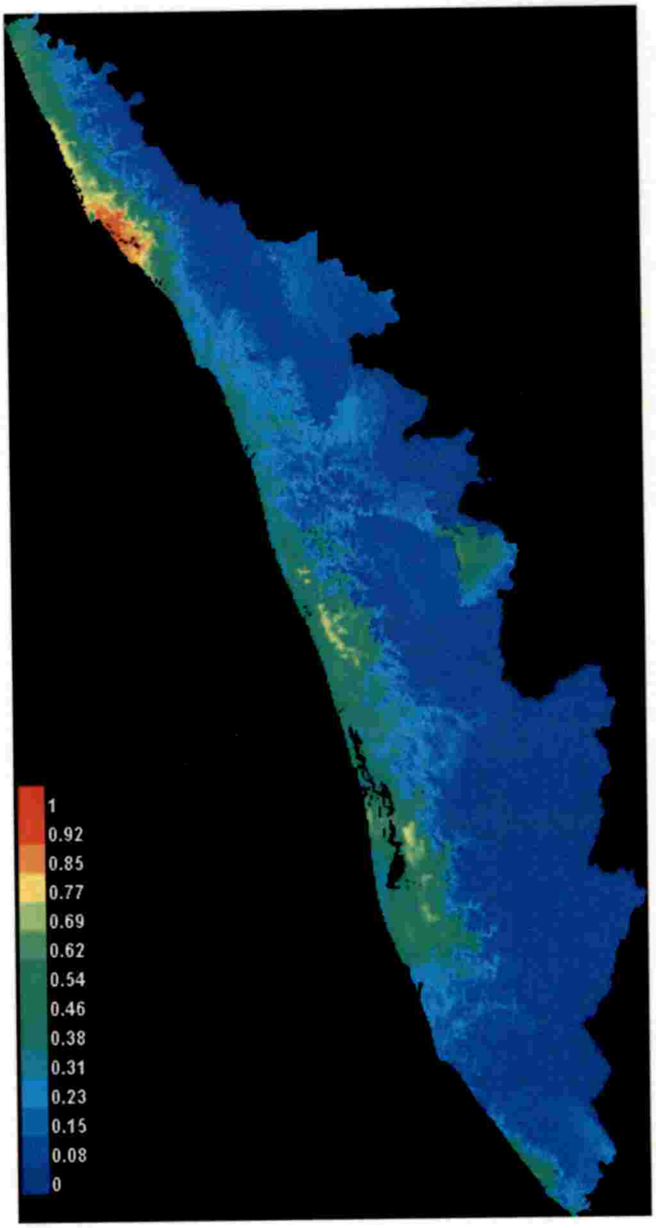

Fig. 48.Current distribution of the Stonechat in Kerala

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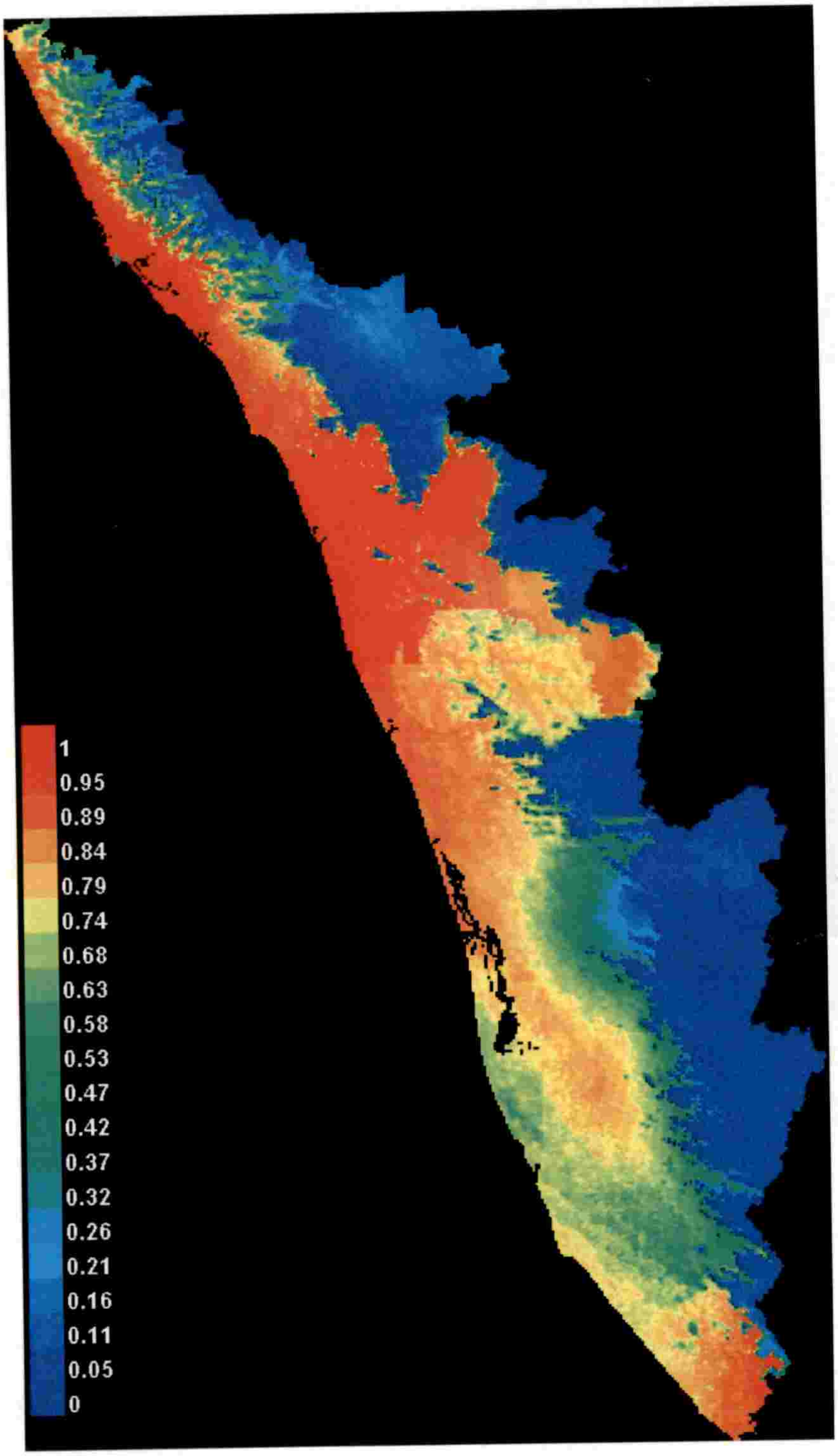


Fig. 49. Prediction of the future distribution of the Stonechat for 2050 under RCP2.6 prediction

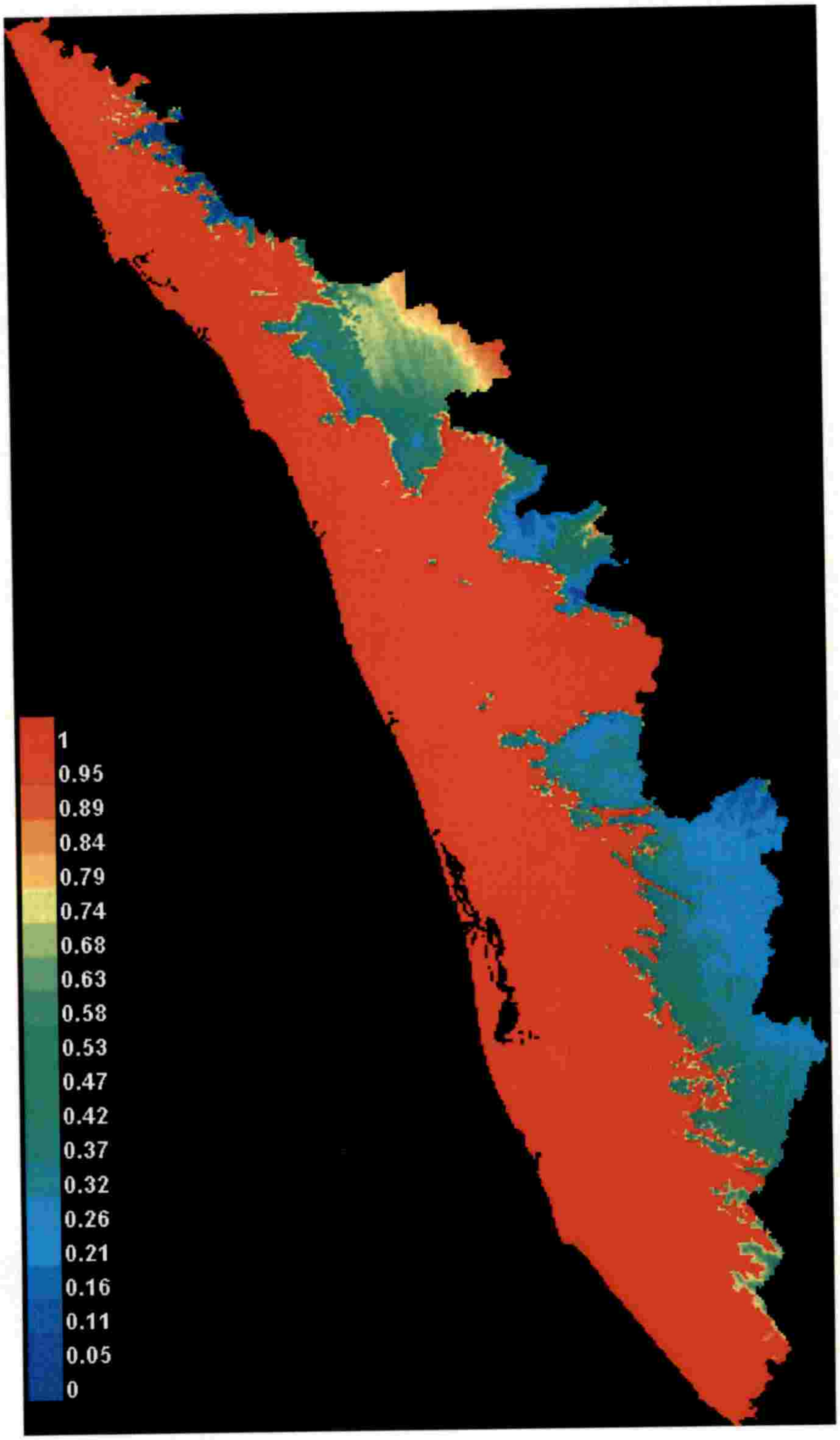


Fig. 50. Prediction of the future distribution of the Stonechat for 2050 under RCP4.5 prediction

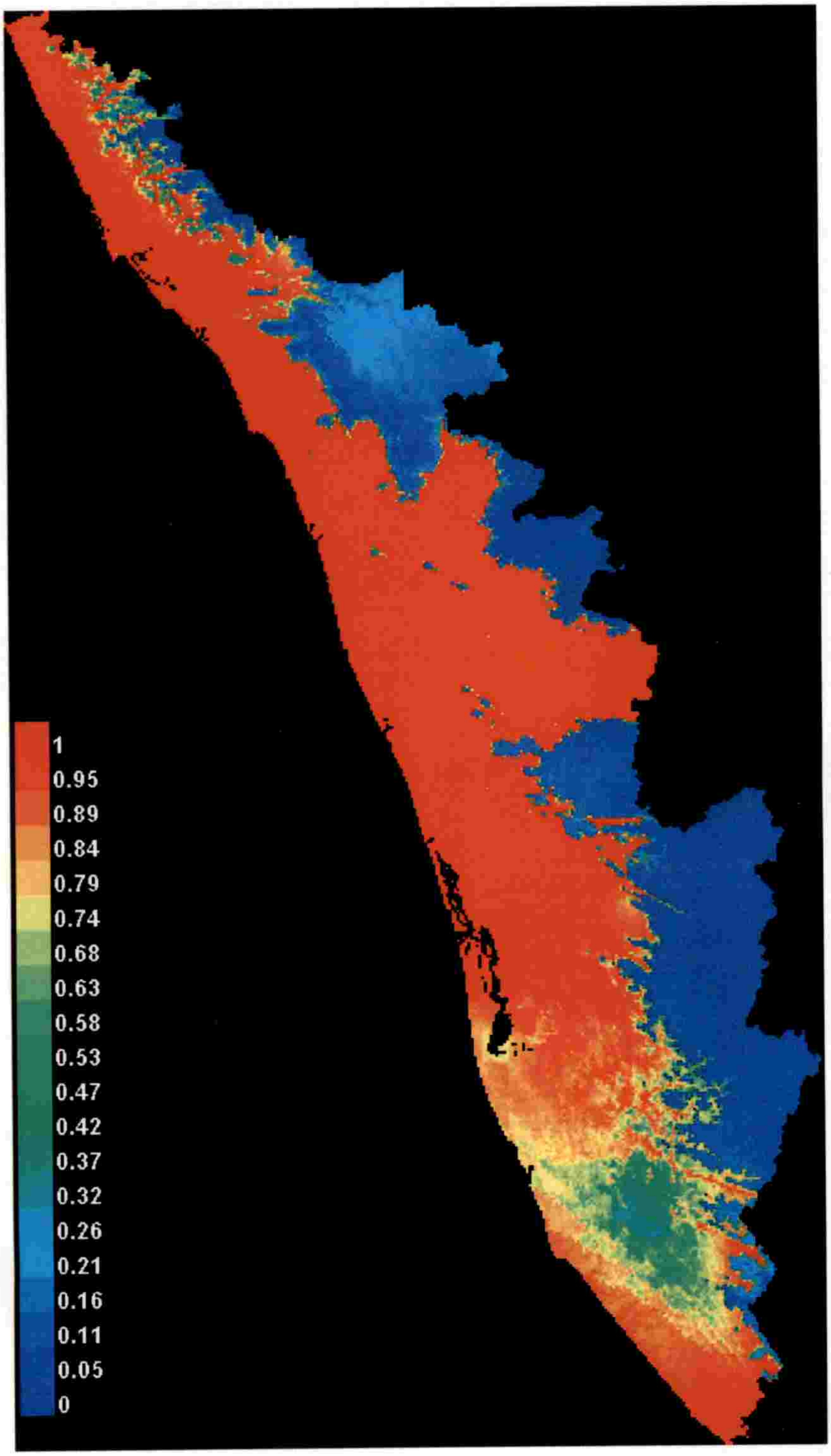


Fig. 51. Prediction of the future distribution of the Stonechat for 2050 under RCP6.0 prediction

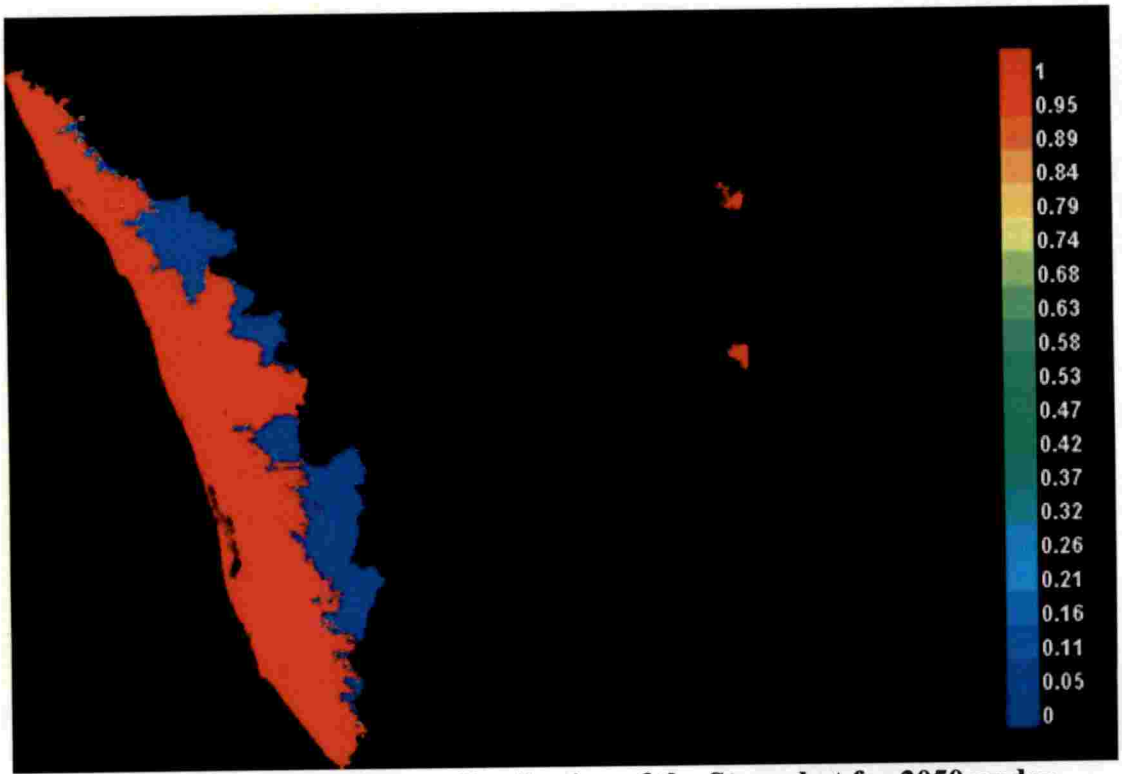


Fig. 52. Prediction of the future distribution of the Stonechat for 2050 under RCP8.5 prediction

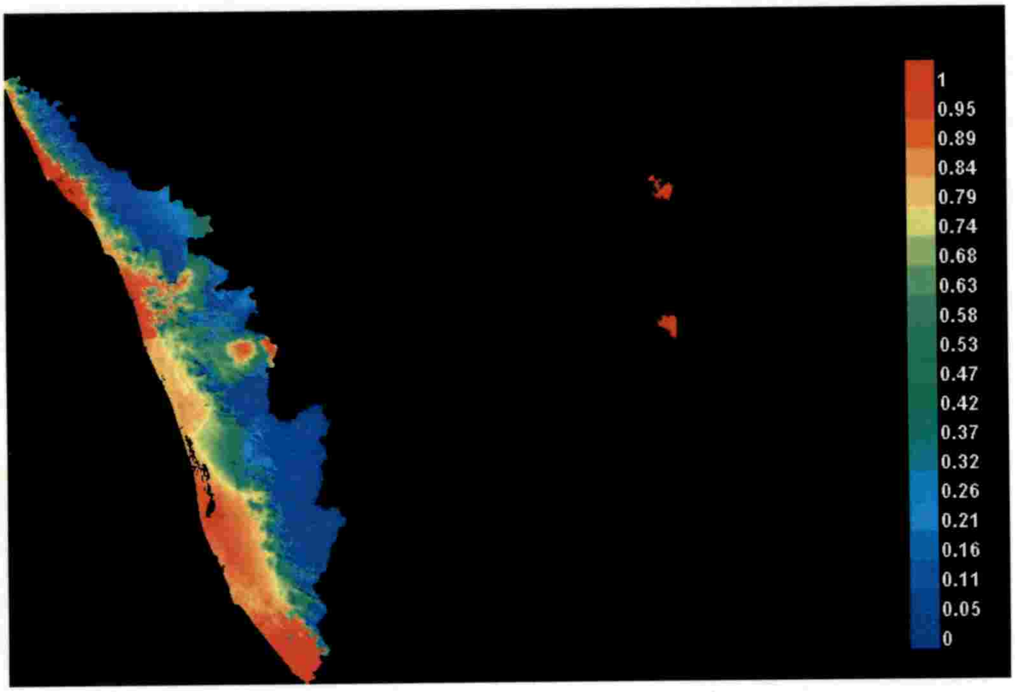


Fig. 53. Prediction of the future distribution of the Stonechat for 2070 under RCP2.6 prediction

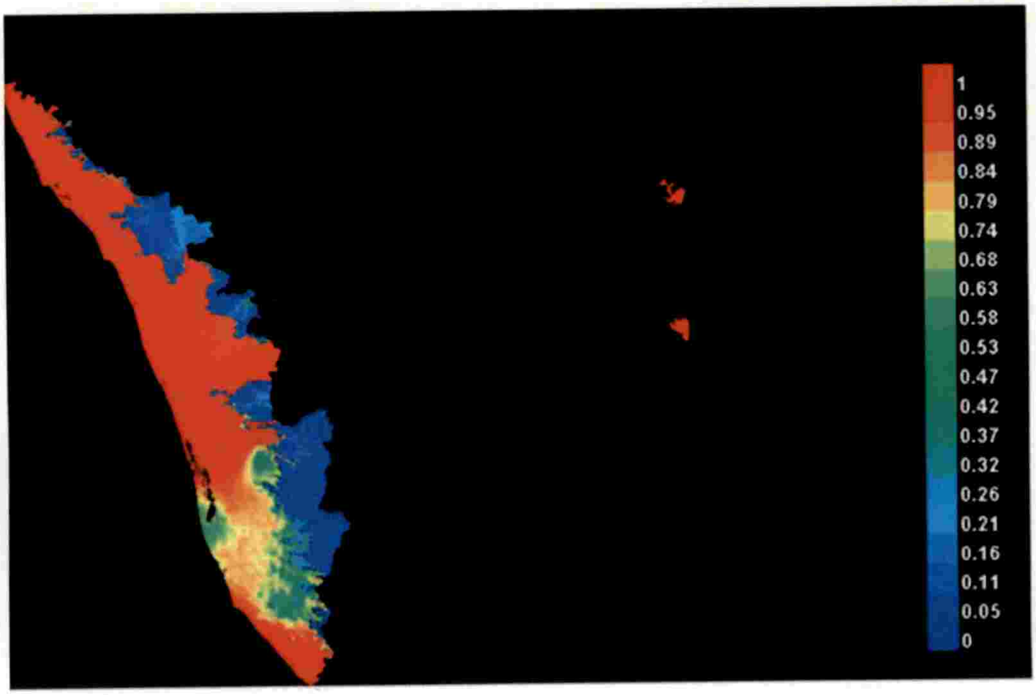


Fig. 54. Prediction of the future distribution of the Stonechat for 2070 under RCP4.5 prediction

Fig. 55. Prediction of the future distribution of the Stonechat for 2070 under RCP6.0 prediction

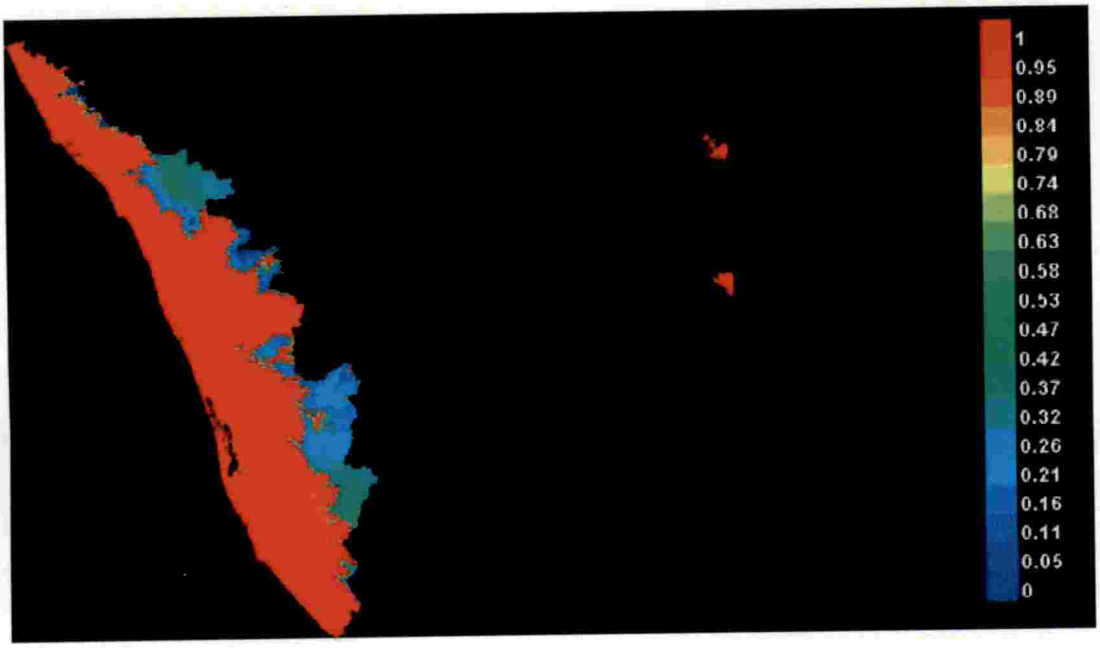


Fig. 56. Prediction of the future distribution of the Stonechat for 2070 under RCP8.5 prediction

4.5 GREATER-SPOTTED EAGLE

After analysing the AUC values and SD, the best model out of the four trials were selected for the Greater-spotted eagle.

Table. 10. Average test AUC values and SD of each model of the distribution of the Greater-spotted Eagle

Model trial no.	AUC values	SD
1	0.896	0.076
2	0.874	0.068
3	0.894	0.053
4	0.893	0.039

For the Greater-spotted eagle, four trial models were run and among them the first model was selected best for determining its current and future distribution.

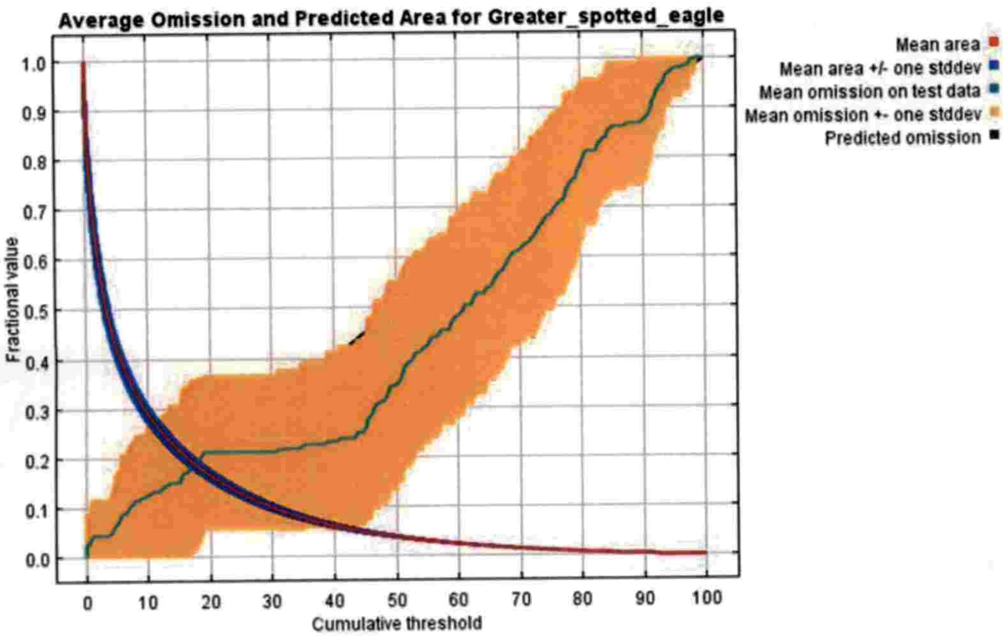


Figure. 57. shows the Test omission rate and predicted area as a function of the cumulative threshold, averaged over the replicate runs

Here the omission line was passing nearest to the predicted omission line but not following a continuous curve.

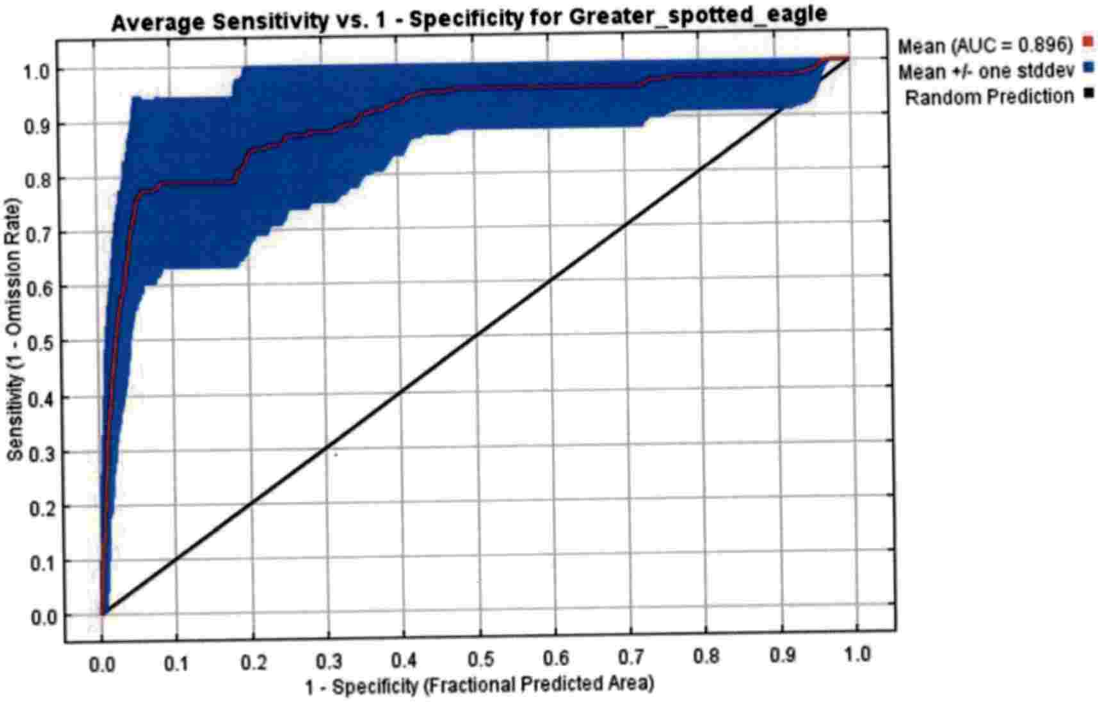
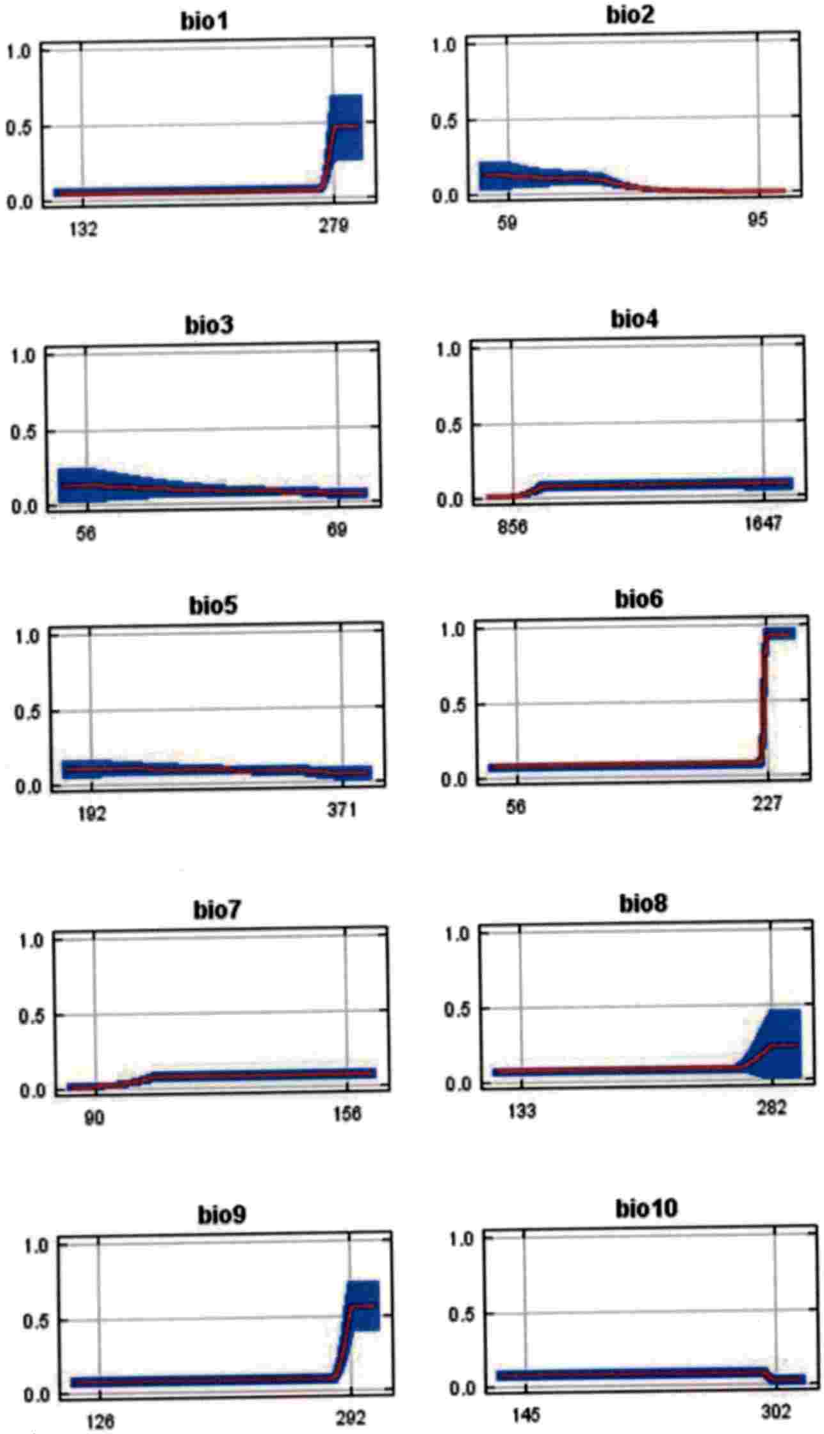


Fig. 58. depicts the ROC curve averaged over the replicated runs of the given model for Greater-spotted Eagle

For the given model, the ROC curve had shifted to the left top bottom above the predicted omission line.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0.5
0.0
132
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bio2
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0.5
0.0
59
95
bio3
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0.5
0.0
56
69
bio4
1.0
0.5
0.0
856
1647
bio5
1.0
0.5
0.0
192
371
bio6
1.0
0.5
0.0
56
227
bio7
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0.5
0.0
90
156
bio8
1.0
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bio9
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126
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bio10
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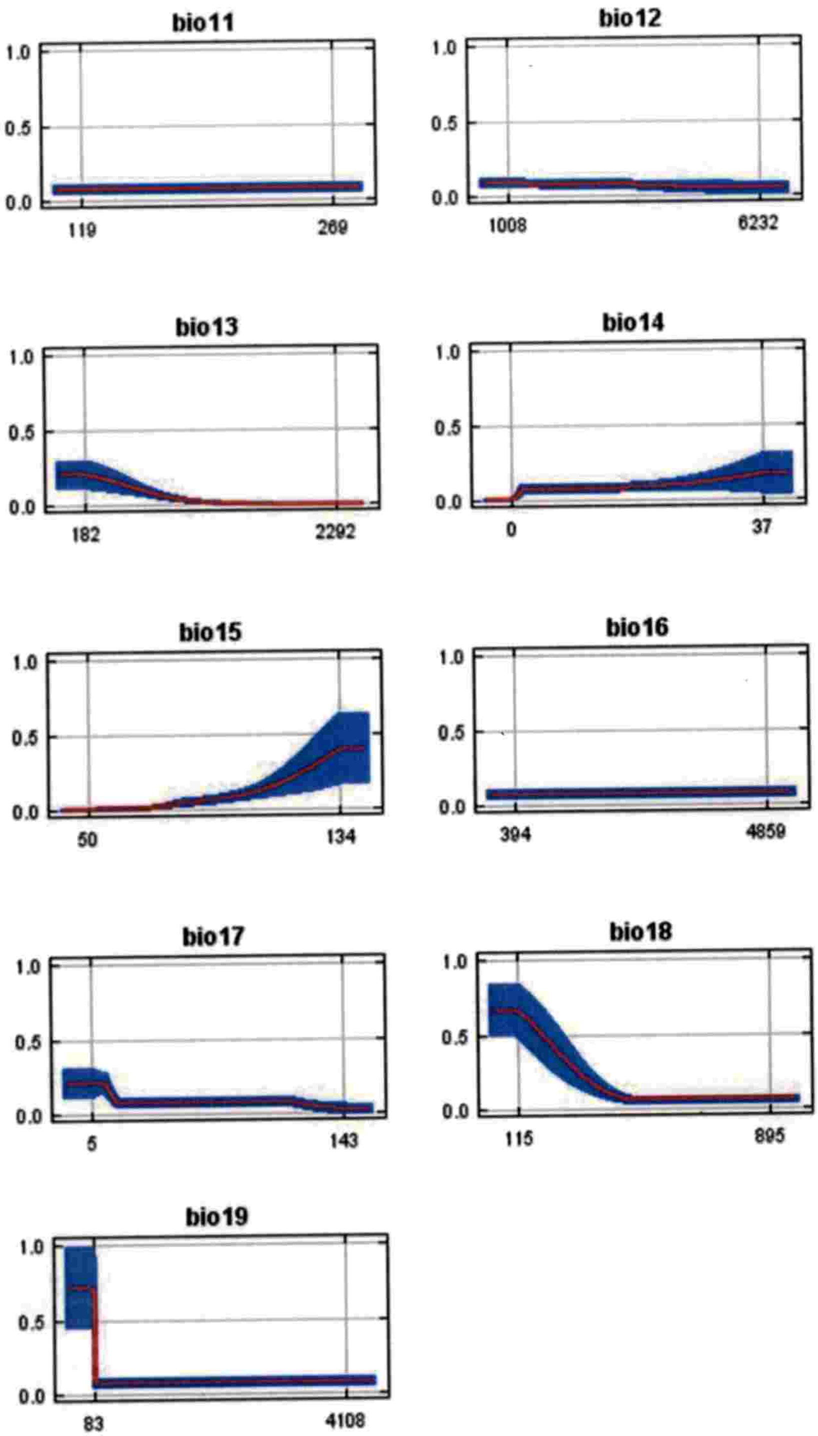
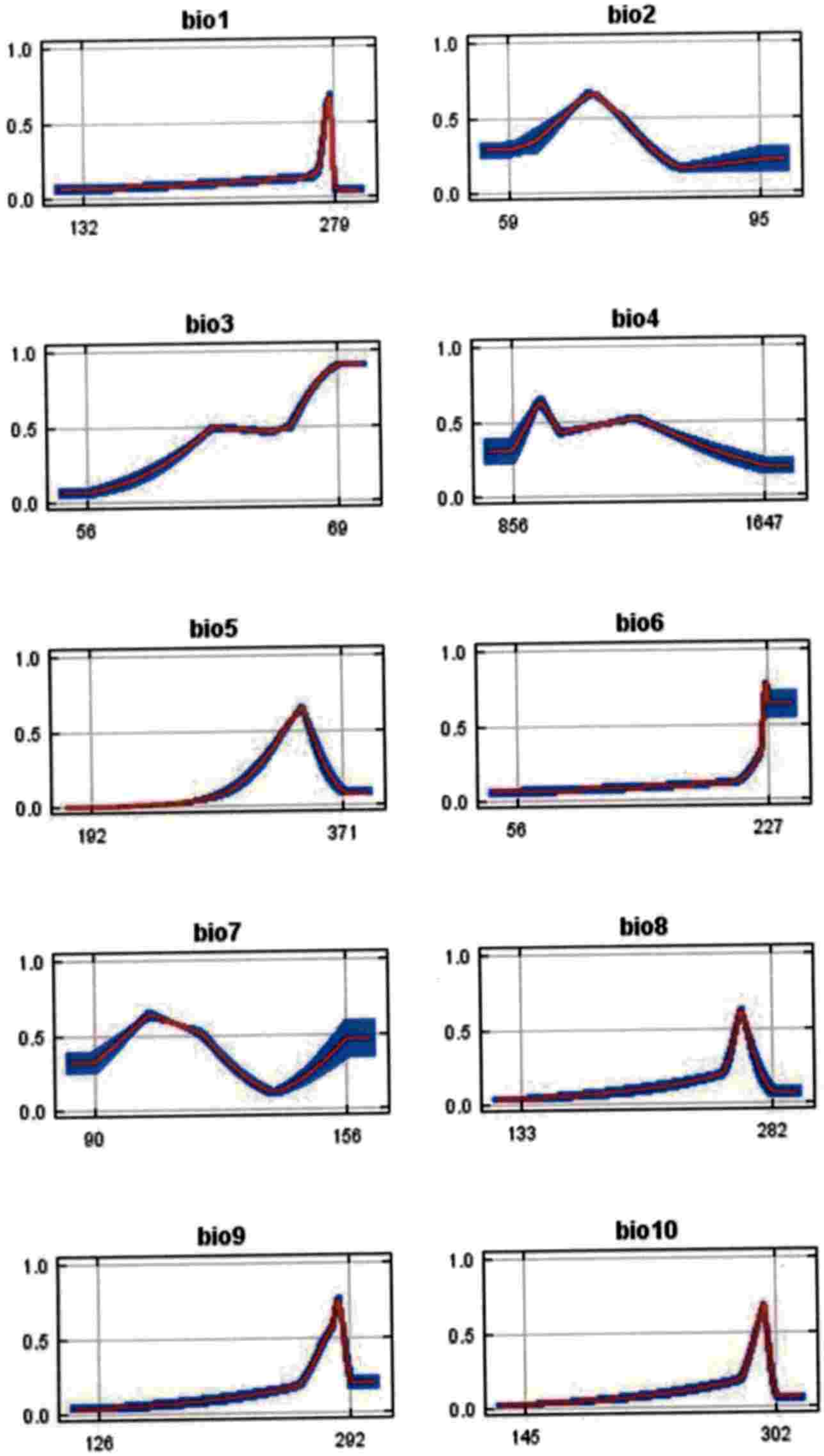


Fig. 59. Response curves of each variable in the distribution of the Greater-spotted Eagle keeping all other variables at their average values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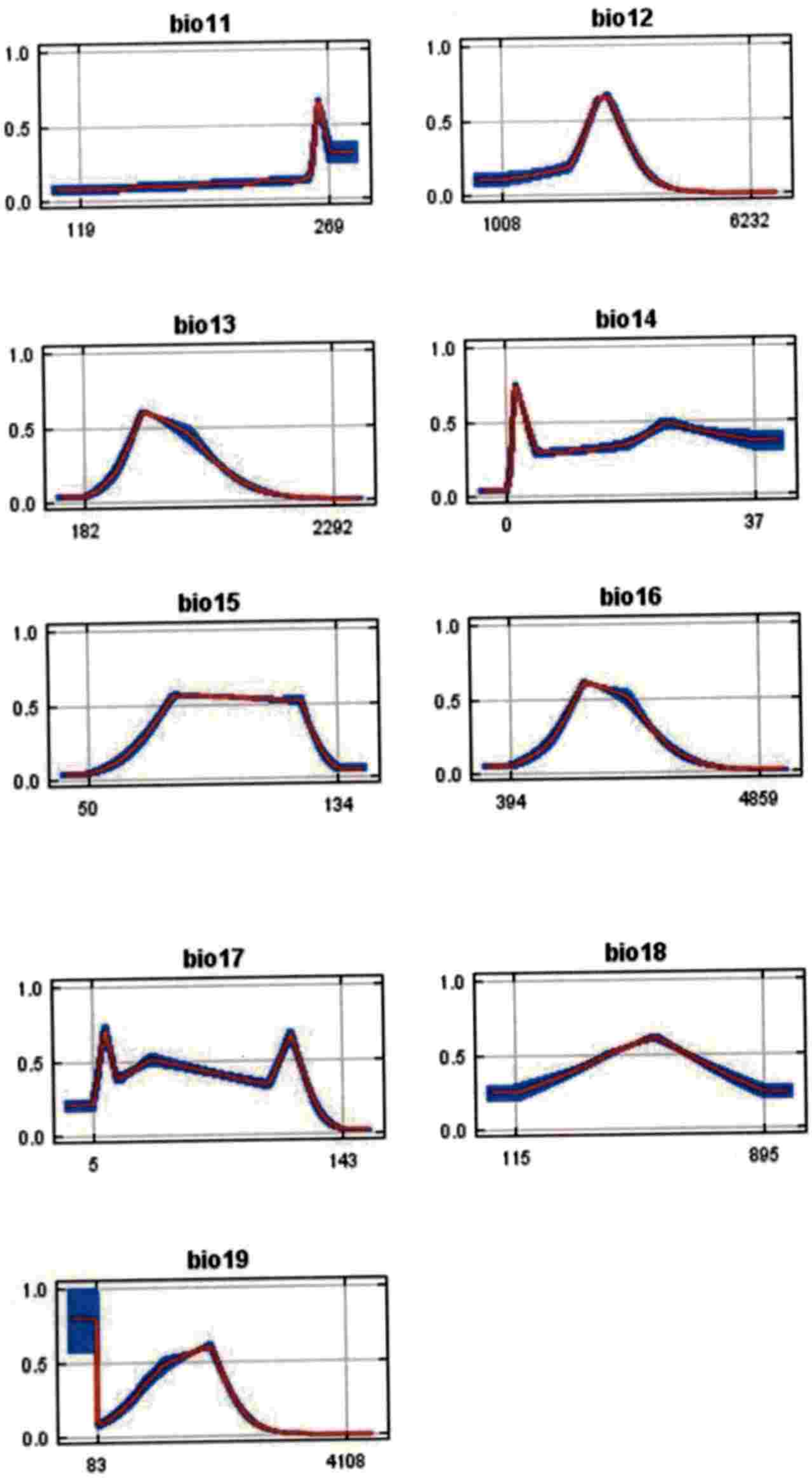


Fig.33. Response curves of each variable in determining the distribution of the Greater-spotted Eagle created using only the corresponding variable

4.5.1 VARIABLE CONTRIBUTION TO THE MODEL DISTRIBUTION OF THE GREATER-SPOTTED EAGLE

Table. 11. Percent contribution and permutation importance of all environmental variables to the model for the Greater-spotted Eagle

Variable	Percent contribution	Permutation importance
Bio6	45	25.1
Bio19	15	2.2
Bio9	9	1.7
Bio17	7.6	3.4
Bio4	4.9	0.5
Bio1	4.6	7.8
Bio14	2.3	1.9
Bio7	2.3	2.1
Bio12	2.1	0.2
Bio5	2	0.5
Bio18	1.3	6.2
Bio2	1.3	15.7
Bio15	1	17.3
Bio13	0.6	12.1
Bio10	0.6	2
Bio8	0.1	0.4
Bio3	0.1	0.8
Bio16	0.1	0
Bio11	0.1	0.1

The percent contribution and permutation importance of all the environmental variables are given by the MaxEnt output and it is shown in Table. 11. Among the variables, the mean temperature of the coldest month (bio6) showed a high percent contribution of about 45. The variable bio19 showed a percent value of 15. Remaining variables had a percent contribution only less than 10. In the case of permutation importance also bio6 showed the greatest value, next to that were variables bio15 and bio2 with values as 17.3 and 15.7 respectively. The other variables showed less permutation importance regarding the distribution of species.

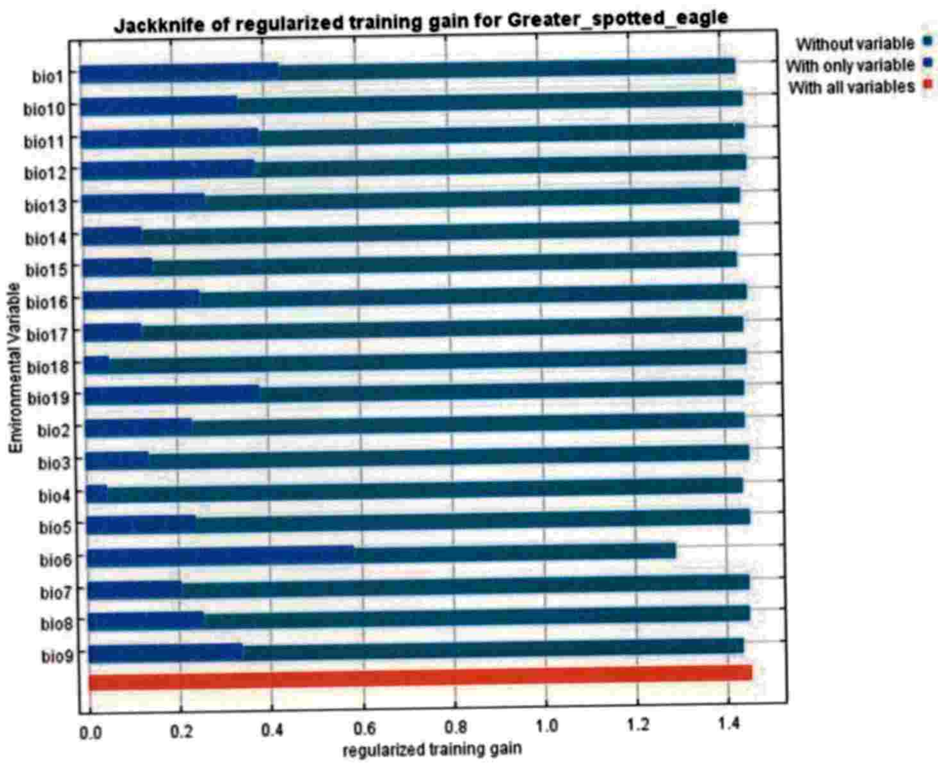


Fig. 61. Jackknife analysis of regularized training gain for the Greater-spotted Eagle using all the variables

The results of the jackknife test of variable importance shown in Fig. 61. tell that the environmental variable with highest gain when used in isolation was bio6, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is bio6, which therefore appears to have the most information that isn't present in the other variables.

The response curves from the MaxEnt output (Fig. 59) are the curves with logistic prediction changes as each environmental variable has varied, keeping all other environmental variables at their average sample value. Positive responses were shown by the variables bio1, bio6, bio9 and bio14. The variables bio18 and bio19 showed moderate response to species distribution. Moderate responses were produced by bio2, bio3, bio4, bio5, bio7, bio8, bio10, bio11, bio12, bio13, bio14, bio15, bio16 and bio17.

The response curves from the MaxEnt output (Fig. 60) showed the change in predicted probability when the corresponding variable was only used. Positive responses were shown by the variables bio3,bio6 and bio19. At the same time all the remaining variables showed moderate responses.

4.5.2 Current and future predictions of the distribution of the Greater-spotted Eagle

The current distribution pattern of the Greater-spotted eagle depicted in Fig. 62. showed the occurrence of the Greater-spotted Eagle in the central regions of Kerala. Also the presence had increased to the low lands of Thrissur and some parts of low lands of Kannur. The spread was observed to the low lands of Alappuzha and mid lands of Alappuzha and Kottayam.

The predicted distribution of the Greater-spotted eagle in 2050 under the RCP 2.6 model is given in Fig. 63. There would be a richer abundance of distribution of the Greater-spotted Eagle in some parts of the low lands, mid lands and high lands of Thiruvananthapuram, low lands of Alappuzha, mid lands of Kottayam, low and mid lands of Ernakulam, mid lands and some regions of high lands of Palakkad, low lands and mid lands of Thrissur, low lands, mid lands and some of the areas of high lands of Malappuram, low lands and mid lands of Kozhikode, low lands of Kannur and Kasargode. Eventhough at a least rate, the distribution of the bird would be spread to the entire district of Kollam, areas of low lands of Alappuzha and mid lands of Pathanamthitta.

The predicted distribution of the Greater-spotted Eagle in 2050 under the RCP4.5 model is given in Fig. 64. According to the model, the occurrence of the birds would be expected to increase towards the low lands, mid lands and high lands of Thiruvananthapuram and Kollam, mid lands and some parts of high lands of Pathanamthitta, low lands and mid lands of Alappuzha, mid lands and high lands of Kottayam, low lands, mid lands and high lands of Ernakulam, low lands and mid lands of Thrissur, mid lands and some regions of high lands of Palakkad, low lands, mid lands and some parts of high lands of Malappuram, low lands and mid lands of Malappuram, low lands, mid lands and high lands of Kannur and Kasargode.

The predicted distribution of the Greater-spotted Eagle in 2050 under the RCP6.0 model is given in Fig. 65. The expansion of distribution of the Greater-spotted Eagle would be much greater in the low lands, mid lands and some parts of high lands of Thiruvananthapuram, low lands, mid lands and some of the high land areas of Kollam, some regions of high lands of Pathanamthitta, mid lands and high lands of Kottayam, low lands, mid lands and high lands of Ernakulam, low lands and mid lands of Thrissur, mid lands and some areas of high lands of Palakkad, low lands, mid lands and some areas of high lands of Malappuram, low lands and mid lands of Kozhikode, low lands and mid lands of Kannur and Kasargode. There would be the presence of distribution of the Greater-spotted Eagle in the low lands and midlands of Alappuzha, mid lands of Pathanamthitta at less stronger rate.

The predicted distribution of the Greater-spotted Eagle in 2050 under the RCP8.5 model is given in Fig.66. According to the model, the abundance of distribution of the Greater-spotted eagle would be expanding to the low lands, mid lands and some regions of high lands of Thiruvananthapuram, mid lands and high lands of Kollam, low lands of Alappuzha, high lands of Pathanamthitta, mid lands and high lands of Kottayam, low lands, mid lands and high lands of Ernakulam, low lands and mid lands of Thrissur, mid lands and high lands of Palakkad, low lands, mid lands and high lands of Malappuram, low lands and mid lands of Kasargode and Kozhikode, low lands, high lands and some of the parts of high lands of Kannur. There would be decreased rate of spread to the low lands of Kollam and some areas of low lands of Alappuzha.

The predicted distribution of the in 2070 under the RCP 2.6 model is depicted in Fig. 67. The presence of the Greater-spotted Eagle would be expanding to the lowlands, mid lands and major parts of high lands of Thiruvananthapuram, low lands and mid lands of Kollam, low lands and mid lands of Alappuzha, mid lands of Pathanamthitta, mid lands of Kottayam, low lands and mid lands of Ernakulam, low lands and some of the mid lands of Thrissur, mid lands of Palakkad, low lands and some of the mid land regions of Malappuram, mid lands of Palakkad, low lands of Kannur, Kozhikode and Kasargode.

The predicted distribution of the Greater-spotted Eagle in 2070 under the RCP 4.5 model is depicted in Fig. 68. The distribution of the Greater-spotted Eagle would be expanding to the major portions of low lands, mid lands and high lands of Thiruvananthapuram, some parts of low lands and mid lands of Ernakulam, low lands, mid lands and high lands of Thrissur, mid lands and high lands of Palakkad, low lands, mid lands and high lands of Malappuram, low lands and mid lands of Kozhikode, low lands, mid lands and some of the high land regions of Kannur and Kasargode.

The predicted distribution of the Greater-spotted Eagle in 2070 under the RCP 6.0 model is given in Fig. 69. Here the model predicts that the bird distribution would spread to low, mid and high lands of Thiruvananthapuram, low lands and mid lands of Kollam, low lands and mid lands of Alappuzha, midlands and high lands of Pathanamthitta, midlands and high lands of Kottayam, low lands, mid lands and high lands of Ernakulam, low lands and mid lands of Thrissur, mid lands and major portion of high lands of Palakkad, low lands and mid lands of Kozhikode, low lands, mid lands and high lands of Kannur, low lands and mid lands of Kasargode, low lands, mid lands and major portion of high lands of Malappuram.

The predicted distribution of the Greater-spotted Eagle in 2070 under the RCP 8.5 model is depicted in Fig. 70. According to the model the bird distribution would spread strongly to the low lands, mid lands and high lands of Thiruvananthapuram and Kollam, some regions of high lands of Idukki, low lands and mid lands of Alappuzha, midlands and high lands of Pathanamthitta, low lands, mid lands and high lands of Ernakulam, low lands, mid lands and high lands of Thrissur, mid lands and high lands of Palakkad, low lands and mid lands of Kozhikode, Kannur and Kasargode, low lands, mid lands and high lands of Malappuram.

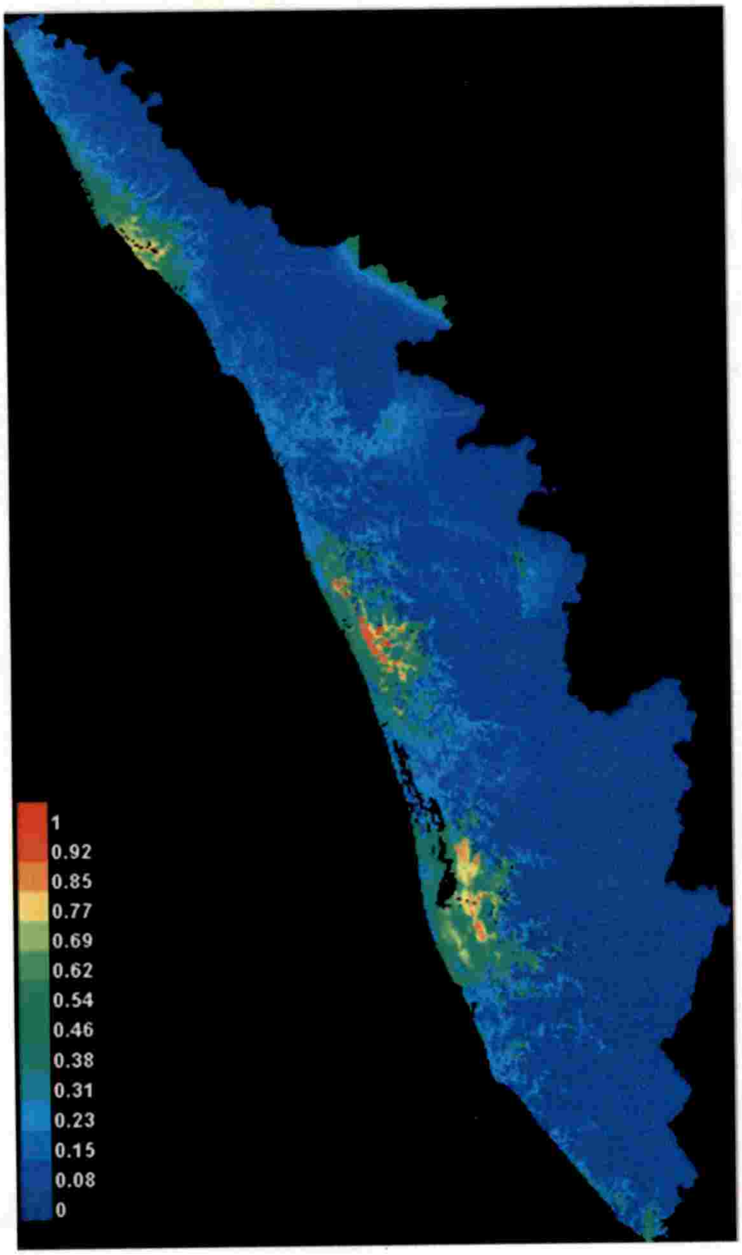


Fig. 62. Current distribution of the Greater-spotted Eagle in Kerala

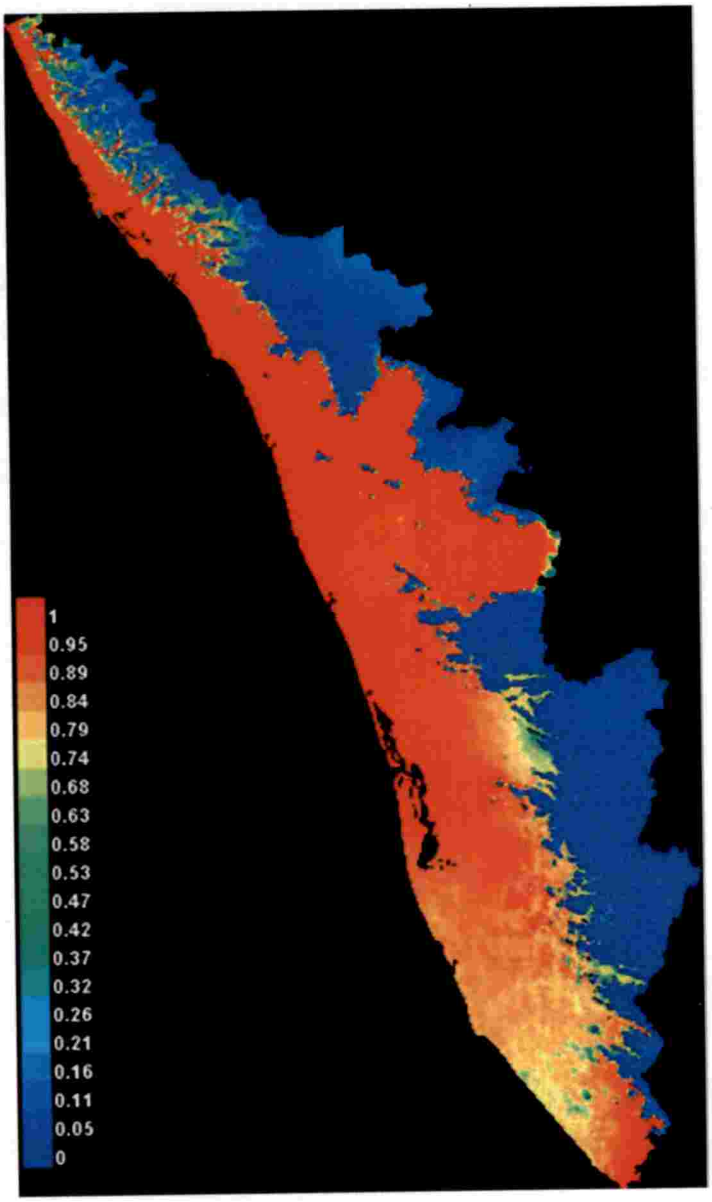


Fig. 63. Prediction of the future distribution of the Greater-spotted Eagle for 2050 under RCP2.6 prediction

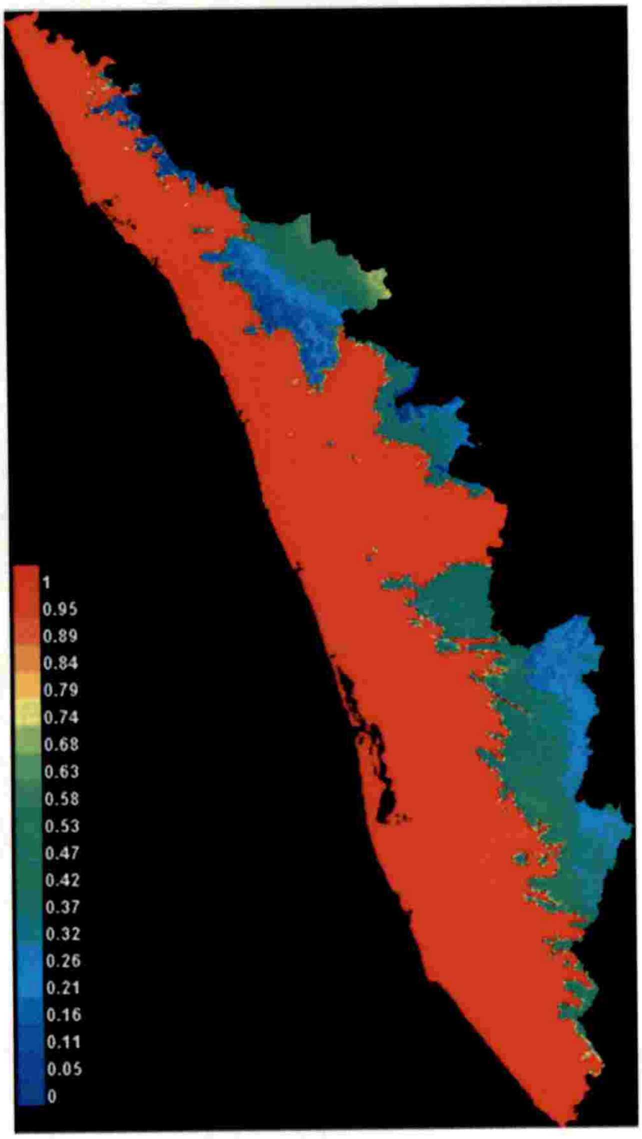


Fig. 64. Prediction of the future distribution of the Greater-spotted Eagle for 2050 under RCP4.5 prediction

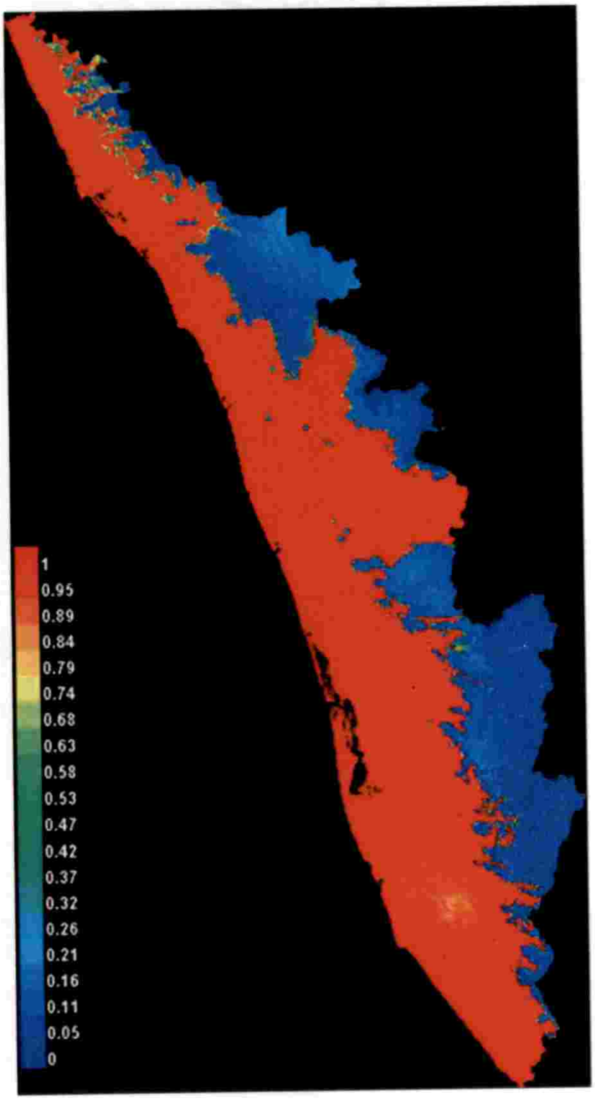


Fig. 65. Prediction of the future distribution of the Greater-spotted Eagle for 2050 under RCP6.0 prediction

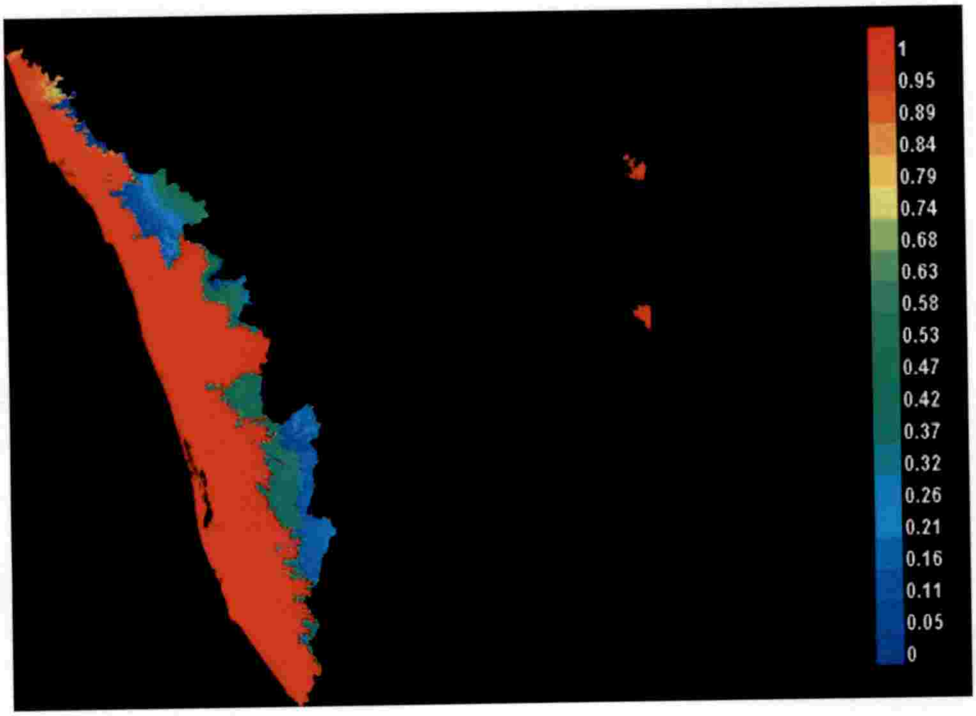


Fig. 66. Prediction of the future distribution of the Greater-spotted Eagle for 2050 underRCP8.5 prediction

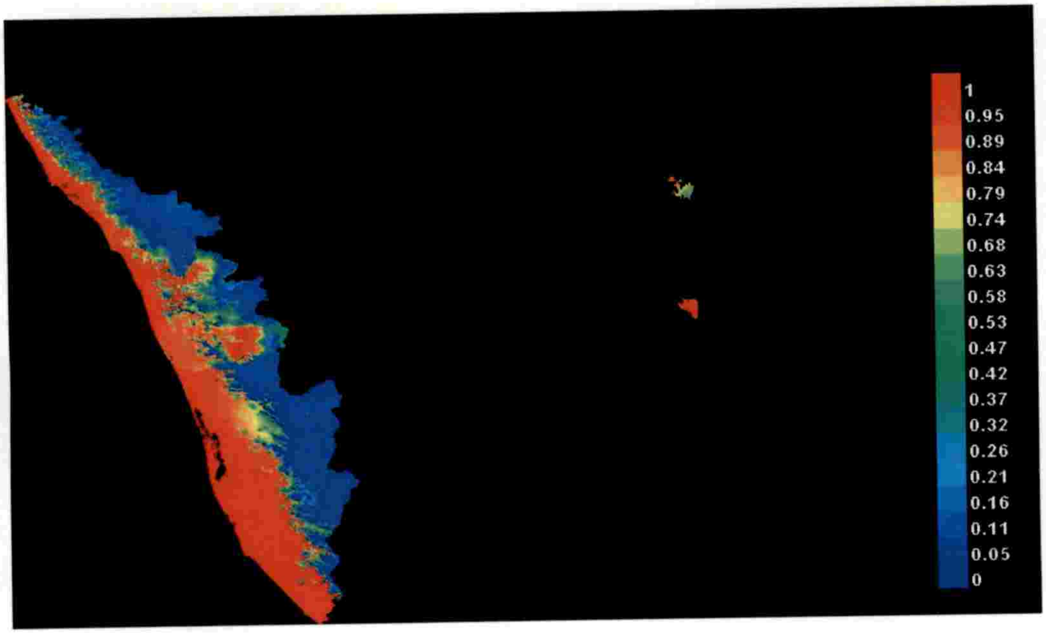


Fig. 67. Prediction of the future distribution of the Greater-spotted Eagle for 2070 under RCP2.6 prediction

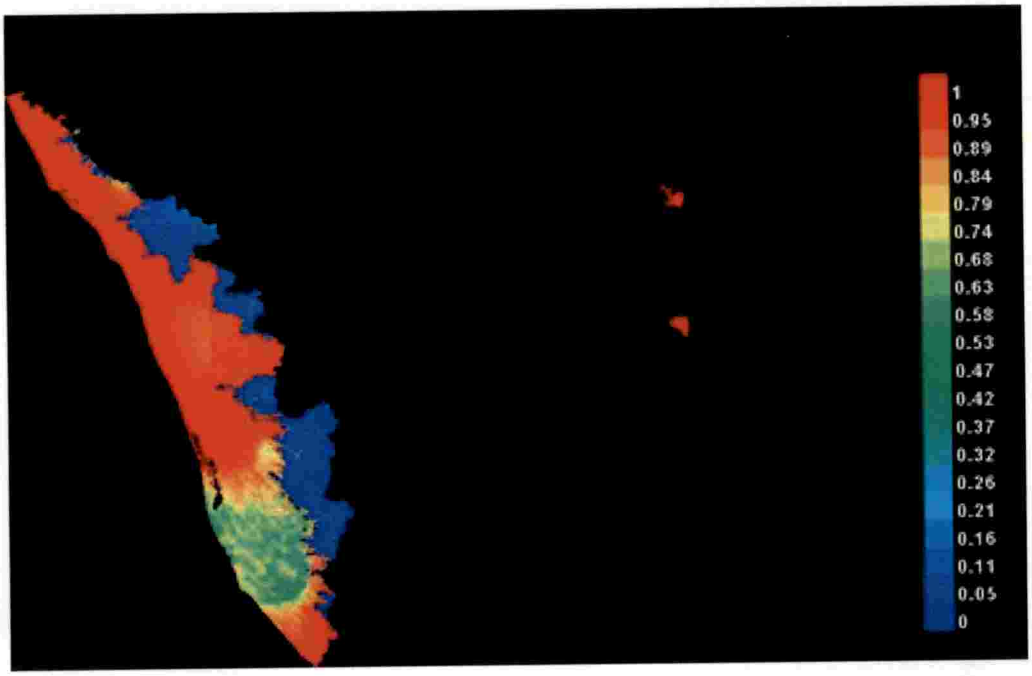


Fig. 68. Prediction of the future distribution of the Greater-spotted Eagle for 2070 under RCP4.5 prediction

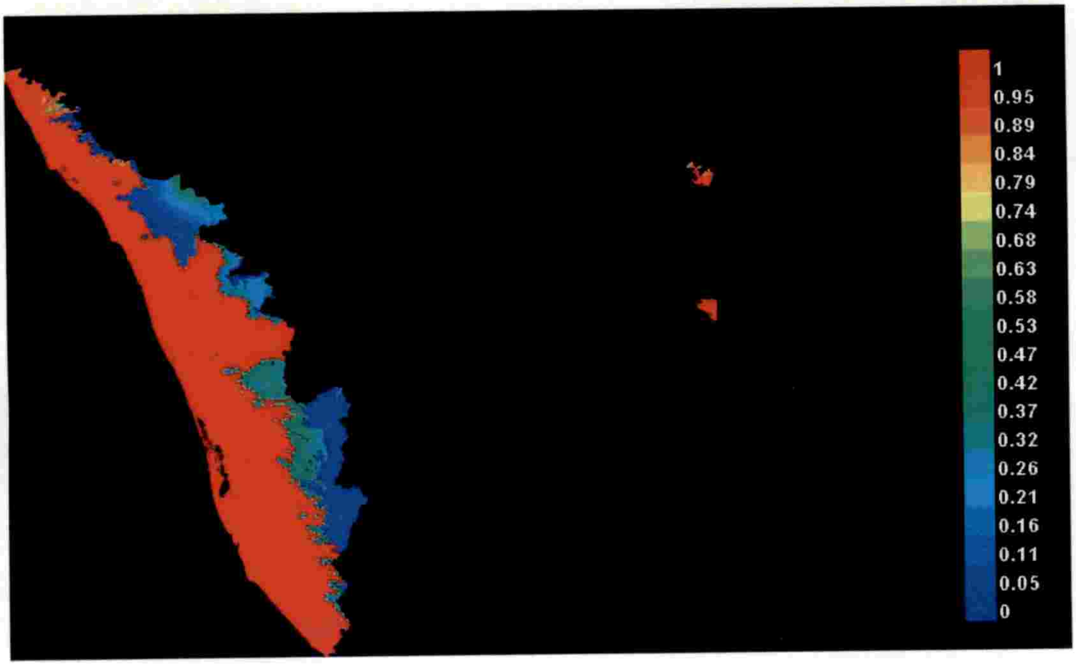


Fig. 69.Prediction of the future distribution of the Greater-spotted Eagle for 2070 under RCP6.0 prediction

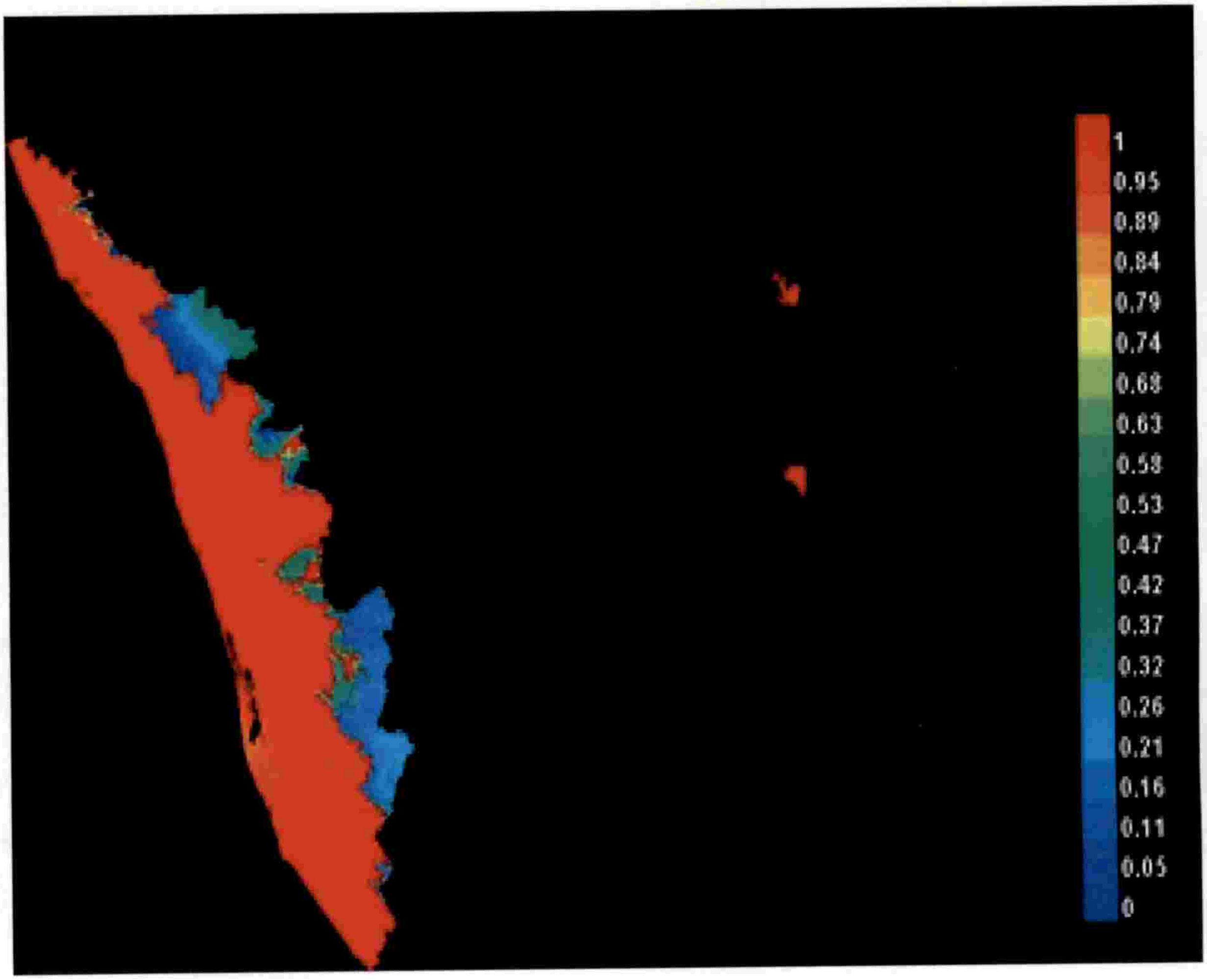


Fig. 70. Prediction of the future distribution of the Greater-spotted Eagle for 2070 under RCP8.5 prediction

4.6 ISABELLINE WHEATEAR

To select the better model for accurate results, 4 different models were run by MaxEnt and the corresponding AUC values and SD were analysed for the given bird.

Table.12. Average test AUC values and SD of each model of the distribution of the Isabelline Wheatear

Model trial no.	AUC values	SD
1	0.602	0.193
2	0.602	0.193
3	0.602	0.193
4	0.604	0.193

For Isabelline Wheatear, out of the four models, fourth one had the maximum AUC value and so it was selected as the better one for further modelling.

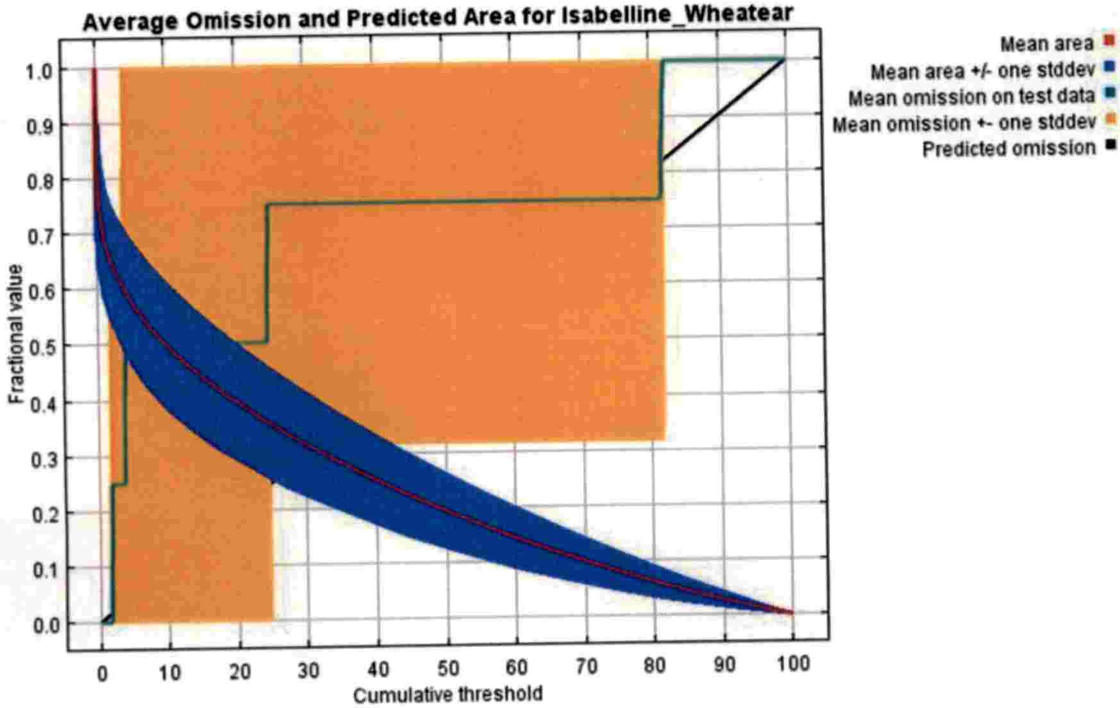


Fig. 71. shows the Test omission rate and predicted area as a function of the cumulative threshold, averaged over the replicate runs for the Isabelline Wheatear

Here the test omission rate does not fit comfortable with the model. There is great variation in the path of mean omission line from predicted omission line.

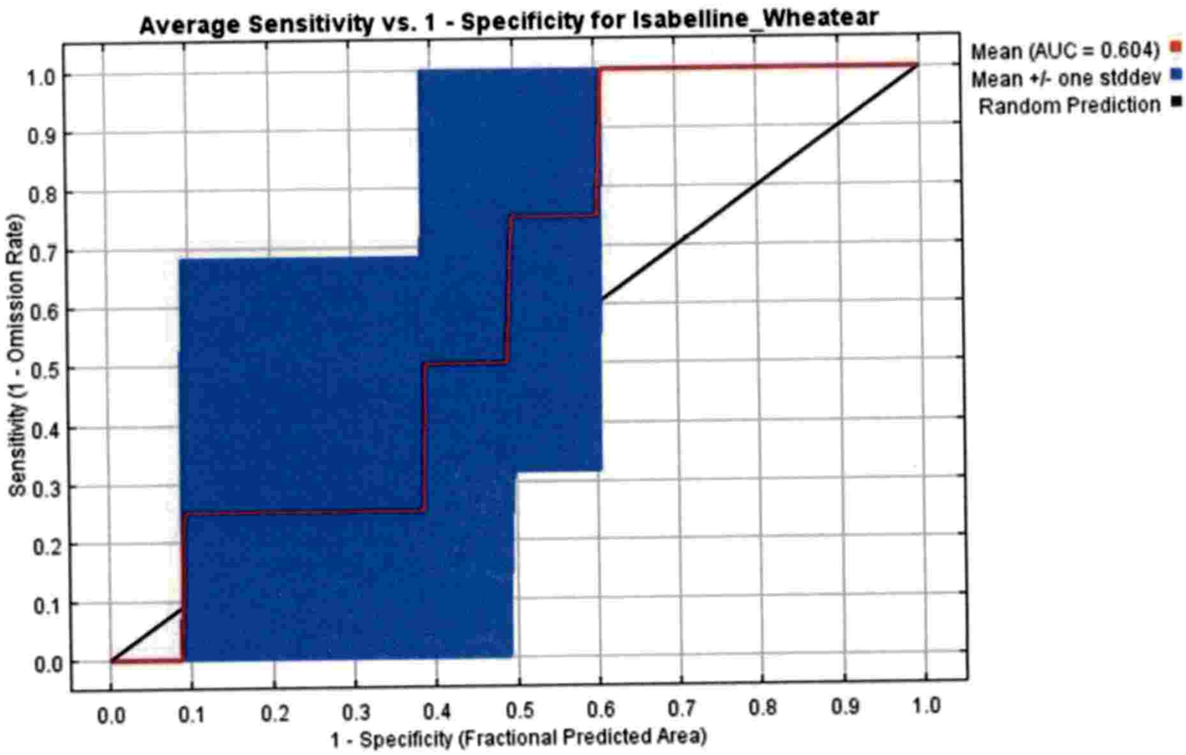
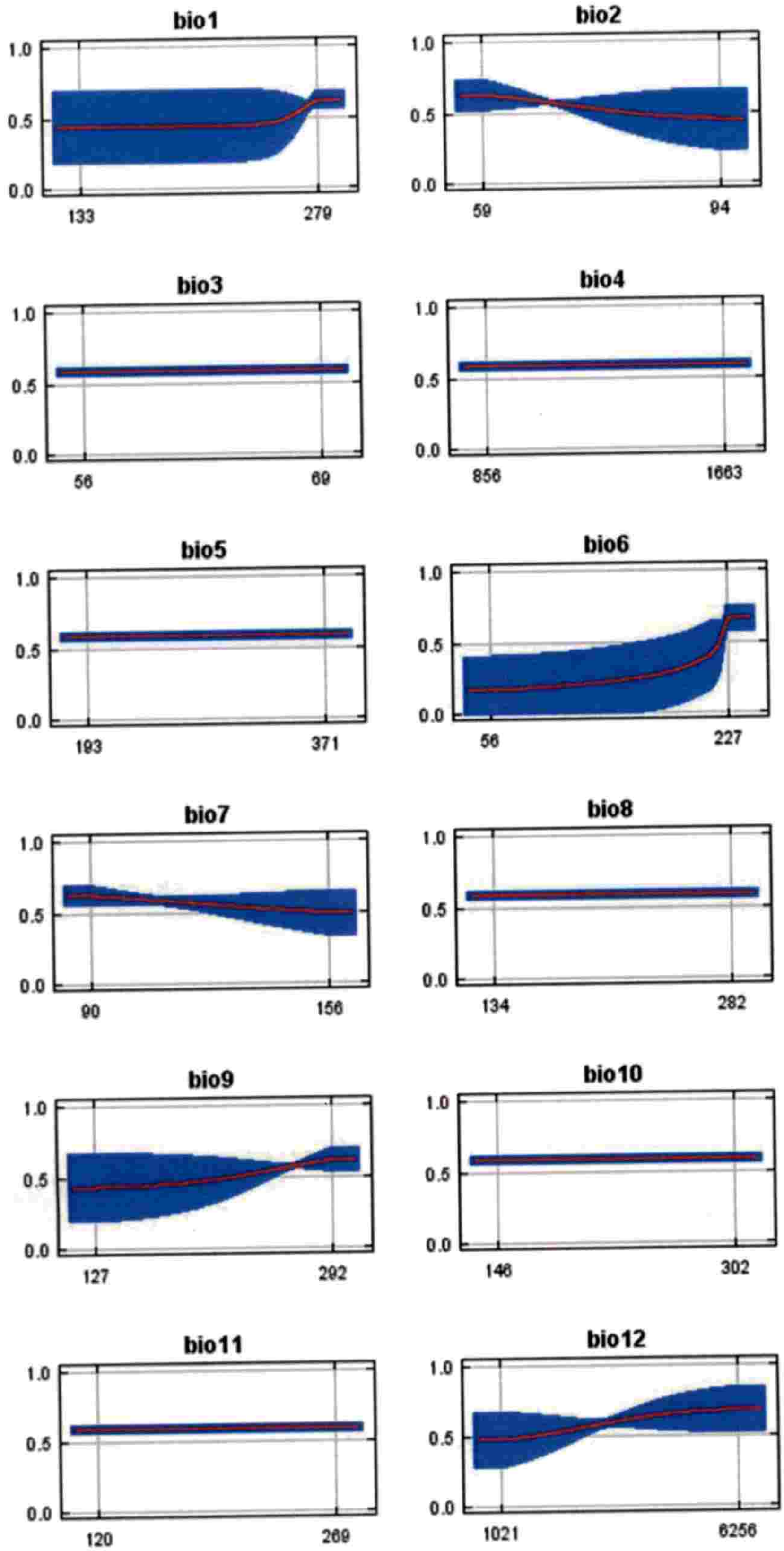


Fig. 72. depicts the ROC curve averaged over the replicated runs of the given model for the Isabelline Wheatear

Eventhough the major portion of the ROC curve was above the random prediction line, the curve didn't shift to the left top of the line. Since the AUC value was 0.604, the model output could be considered well for further modelling processes.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133
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bio2
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0.5
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59
94
bio3
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0.0
56
69
bio4
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0.5
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bio5
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bio6
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0.0
56
227
bio7
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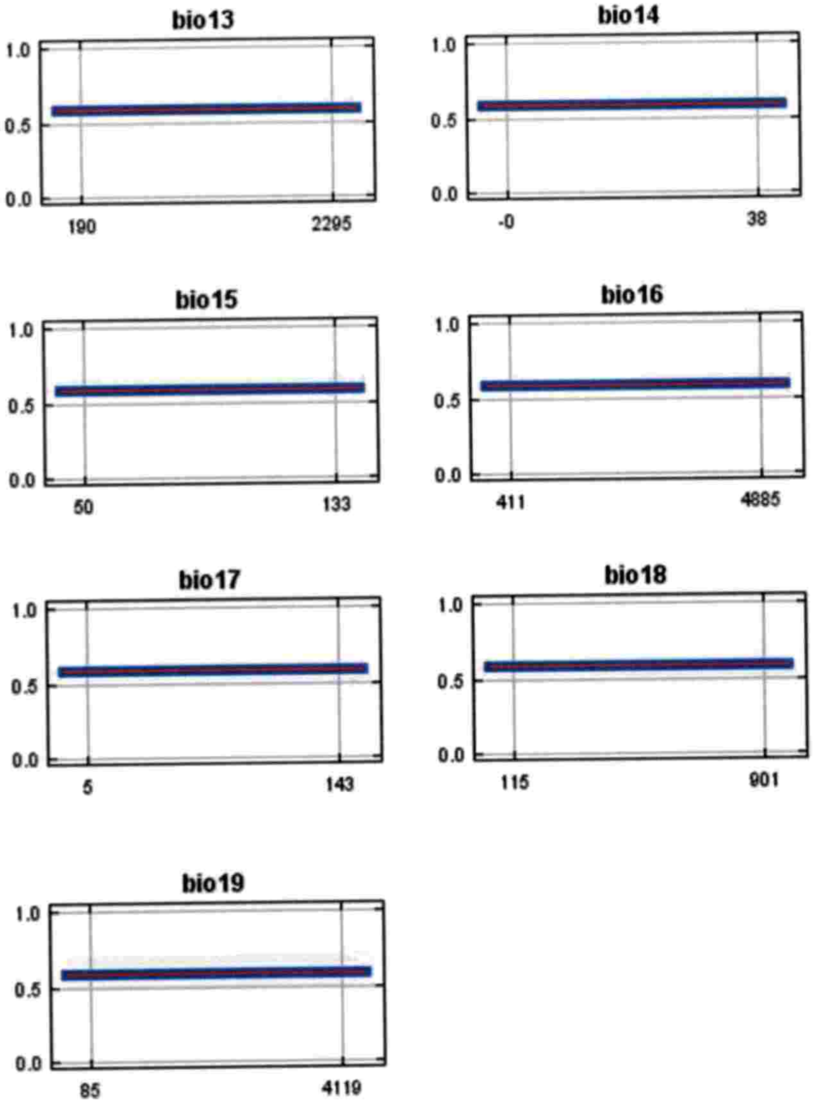
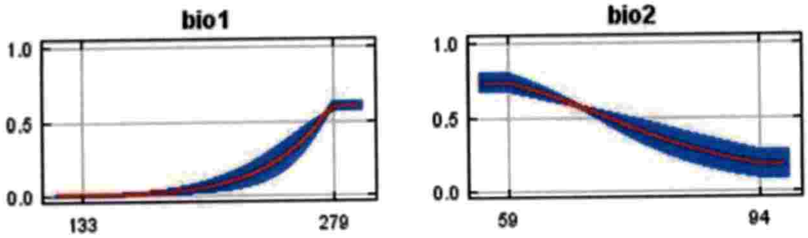
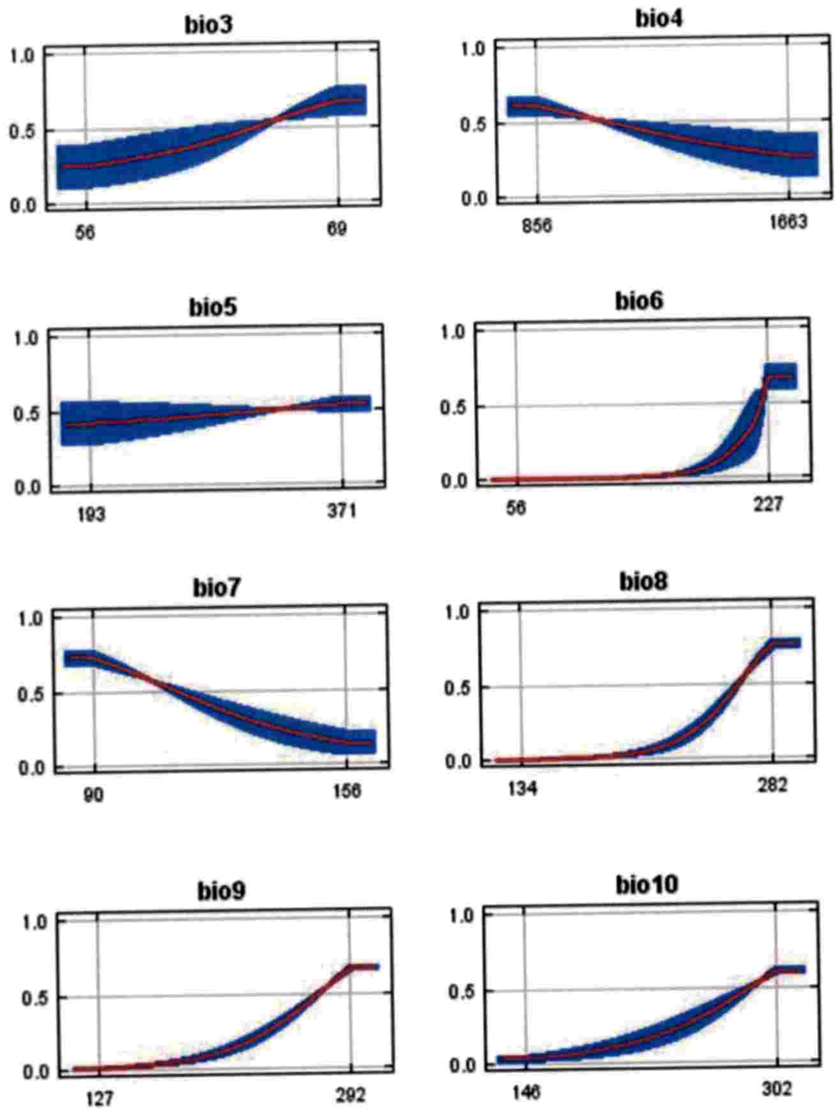


Fig. 73. Response curves of each variable in the distribution of the Isabelline Wheatear keeping all other variables at their average values

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bio6
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bio7
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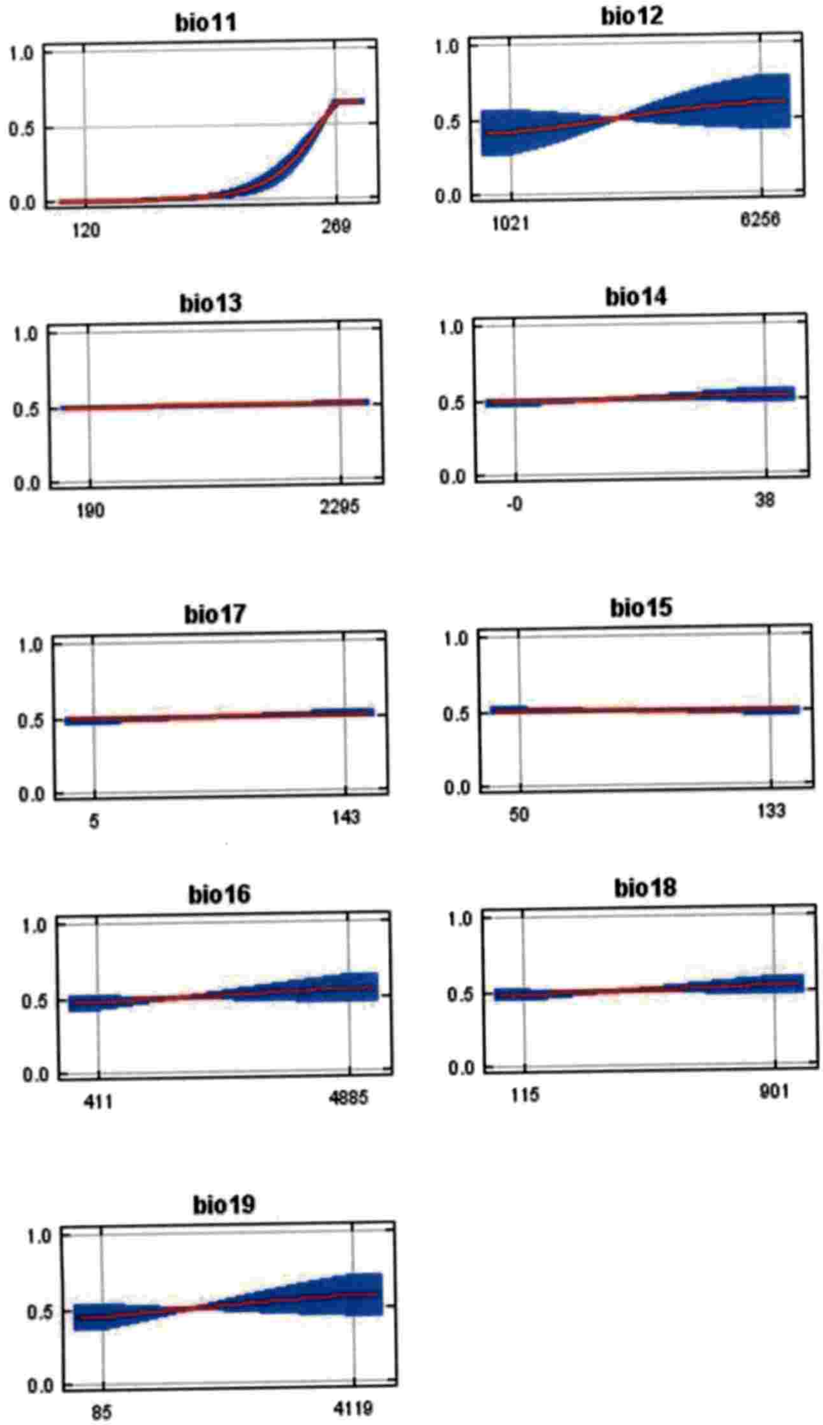

Fig.74. Response curves of each variable in determining the distribution of the Isabelline Wheatear created using only the corresponding variable

4.6.1 VARIABLE CONTRIBUTION TO THE MODEL DISTRIBUTION OF ISABELLINE WHEATEAR

Table. 13. Percent contribution and permutation importance of all environmental variables to the model for the Isabelline Wheatear

Variable	Percent contribution	Permutation importance
Bio6	70.7	50.3
Bio2	9	24.7
Bio12	8.3	5.6
Bio7	5.4	8.2
Bio1	3.5	11.2
Bio3	2.6	0
Bio9	0.4	0
Bio4	0	0
Bio19	0	0
Bio18	0	0
Bio17	0	0
Bio16	0	0
Bio15	0	0
Bio14	0	0
Bio13	0	0
Bio5	0	0
Bio11	0	0
Bio10	0	0
Bio8	0	0

The percent contribution and permutation importance of all the environmental variables are given by the MaxEnt output and it is shown in Table. 13. The mean temperature of the coldest month (bio6) showed a high percent contribution of about70.7. The variables bio2, bio12, bio7, bio1, bio3 and bio9 showed a percent value less than 10. The remaining variables had no contribution at all. In the case of permutation importance also bio6 had the highest value of about 50.3, next to that were variables bio2 and bio1 with values as 24.7 and 11.2 respectively. For the other variables permutation importance was negligible.

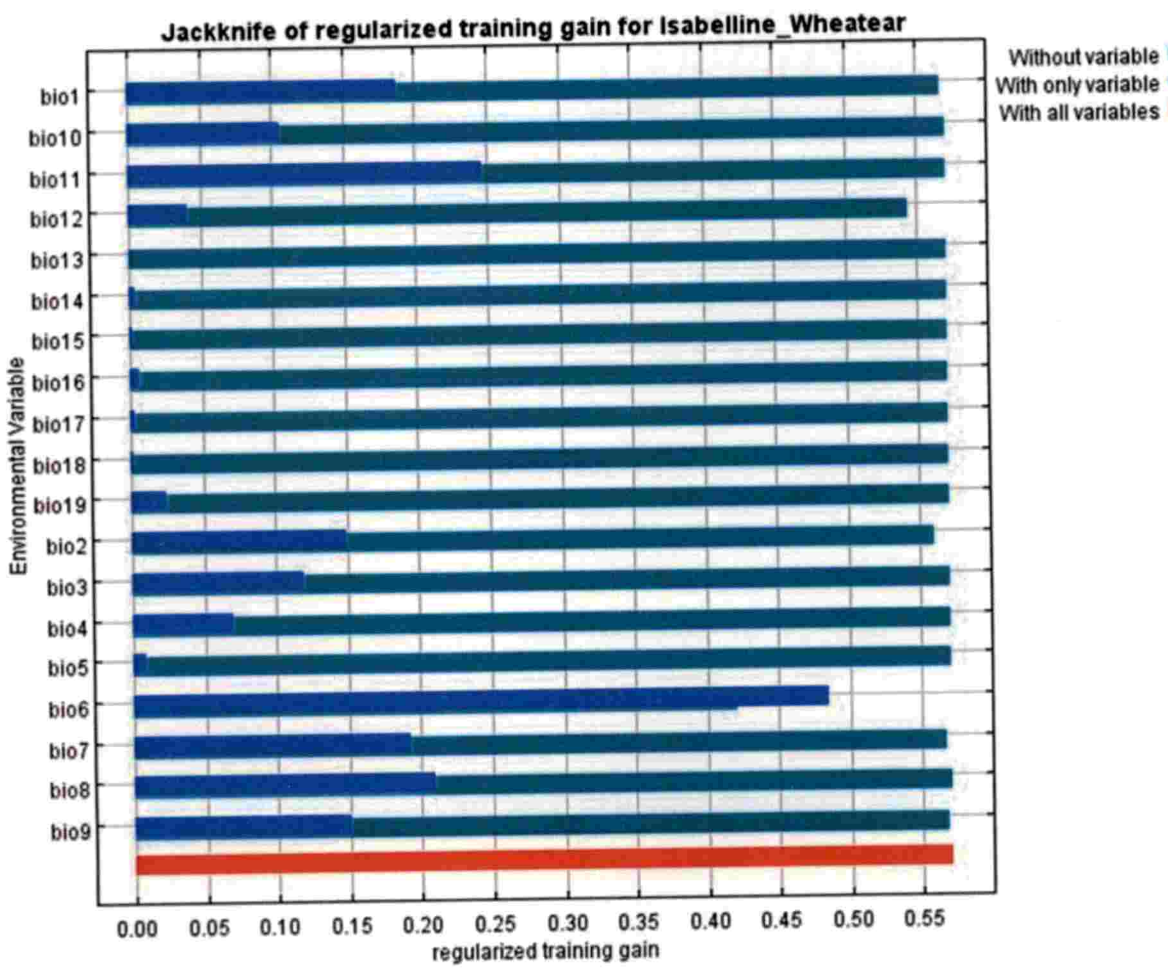

Fig. 75. Jackknife analysis of regularized training gain for the Isabelline Wheatear using all the variables

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The results of the jackknife test of variable importance shown in Fig. 75. tell that the environmental variable with highest gain when used in isolation is bio6, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is bio6, which therefore appears to have the most information that isn't present in the other variables.

The response curves from the MaxEnt output Fig. 73. are the curves with logistic prediction changes as each environmental variable has varied, keeping all other environmental variables at their average sample value. Positive responses were shown by the variables bio1, bio6, bio9 and bio12. In the case of other variables, they showed moderate response to the presence of the migratory bird.

The response curves from the MaxEnt output Fig. 74. showed the change in predicted probability when the corresponding variable was only used. Positive responses were shown by the variables bio1, bio3, bio6, bio8, bio9, bio10 and bio11. At the same time all the remaining variables showed moderate responses.

4.6..2 Current and future predictions of the distribution of the Isabelline Wheatear

The current distribution pattern depicted in Fig. 76. showed the occurrence of the Isabelline Wheatear over the entire plains of Kerala excepting the high lands of Wayanad, Palakkad, Idukki and Kollam. The distribution range was not much stronger as the probability ranged between 50-60 percent.

The predicted distribution of the Isabelline Wheatear in 2050 under the RCP 2.6 model is given in Fig. 77. There would be a richer abundance of distribution of the Isabelline Wheatear in the low lands of Kasargode, mid lands of Kannur, low lands and mid lands of Thiruvananthapuram, Kollam and Alappuzha, mid lands of Pathanamthitta and mid lands and high lands of Kottayam.

The predicted distribution of the Isabelline Wheatear in 2050 under the RCP4.5 model is given in Fig. 78. According to the model, the distribution of Isabelline

Wheatear would expand to the northern and southern regions of Kerala. There would be presence of the bird in the low lands, mid lands and high lands of Thiruvananthapuram and Kollam, low lands of Alappuzha, mid lands of Kottayam and Pathanamthitta, low lands and mid lands of Kozhikode, Kannur and Kasargode with a probability between 68-74 percent. In the central Kerala there would be occurrence of the bird at around 50 percent probability.

The predicted distribution of the Isabelline Wheatear in 2050 under the RCP6.0 model is given in Fig. 79. The expansion of distribution of the Isabelline Wheatear would be expected to be stronger to the southern parts of Kerala mainly towards the low lands, mid lands and high lands of Thiruvananthapuram, low lands and mid lands of Kollam, mid lands of Pathanamthitta and Kottayam, low lands and mid lands of Alappuzha, low lands of Kannur and Kasargode.

The predicted distribution of the Isabelline Wheatear in 2050 under the RCP8.5 model is given in Fig. 80. According to the model, the abundance of distribution of the Isabelline Wheatear would expand to the northern and somewhat central to Southern parts of Kerala. The distribution would spread to the low lands, mid lands and high lands of Thiruvananthapuram, low lands and mid lands of Kollam, mid lands of Pathanamthitta and Kottayam, low lands and mid lands of Alappuzha, low lands and mid lands of Kannur and Kasargode.

The predicted distribution of the Isabelline Wheatear in 2070 under the RCP 2.6 model is depicted in Fig. 81. The occurrence of Isabelline Wheatear would be expanding to the lowlands of Kasargode, low lands of Alappuzha, mid and high lands of Kottayam, mid lands of Pathanamthitta and low and mid lands of Kollam.

The predicted distribution of the Isabelline Wheatear in 2070 under the RCP 4.5 model is depicted in Fig. 82. The distribution of the Isabelline Wheatear would be expanding to the southern regions especially to the low lands of Kollam and low lands of Kasargode.

The predicted distribution of the Isabelline Wheatear in 2070 under the RCP 6.0 model is given in Fig. 83. Here the model predicts that the bird distribution would spread to low, mid and high lands of Kasargode, low lands and mid lands of Kannur and Kozhikode and entire southern parts of Kerala.

The predicted distribution of the Isabelline Wheatear in 2070 under the RCP 8.5 model is depicted in Fig. 84. According to the model the bird distribution would spread to the northern and southern regions of Kerala at a probability rate of 74 percent. The result is almost similar to that of the 2070rcp 8.5 model.

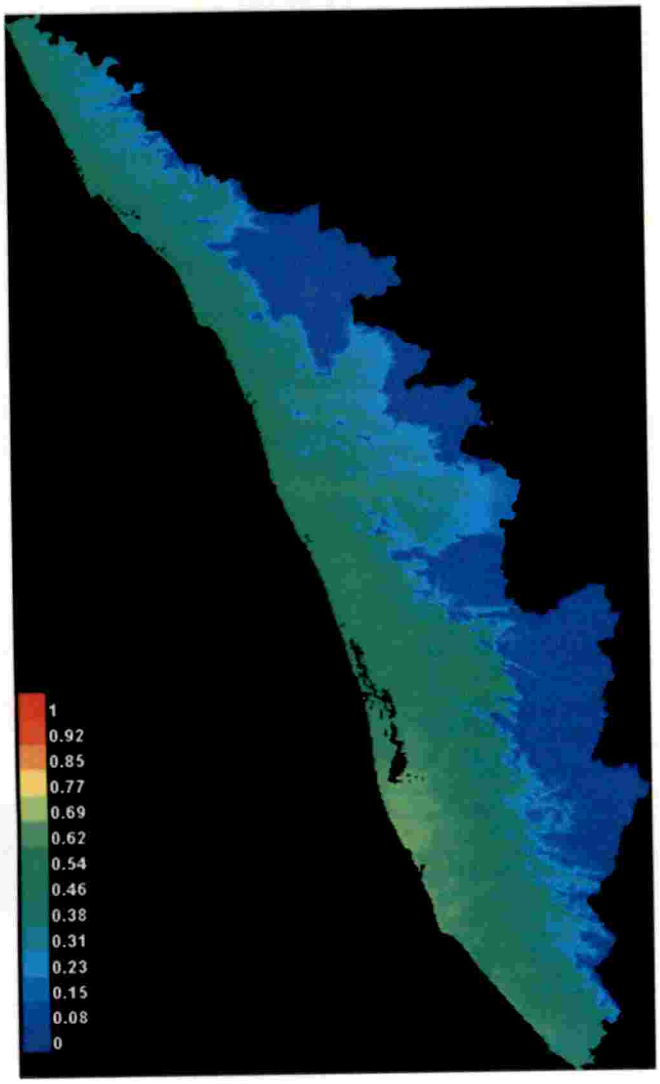

Fig. 76.Current distribution of the Isabelline Wheatear in Kerala

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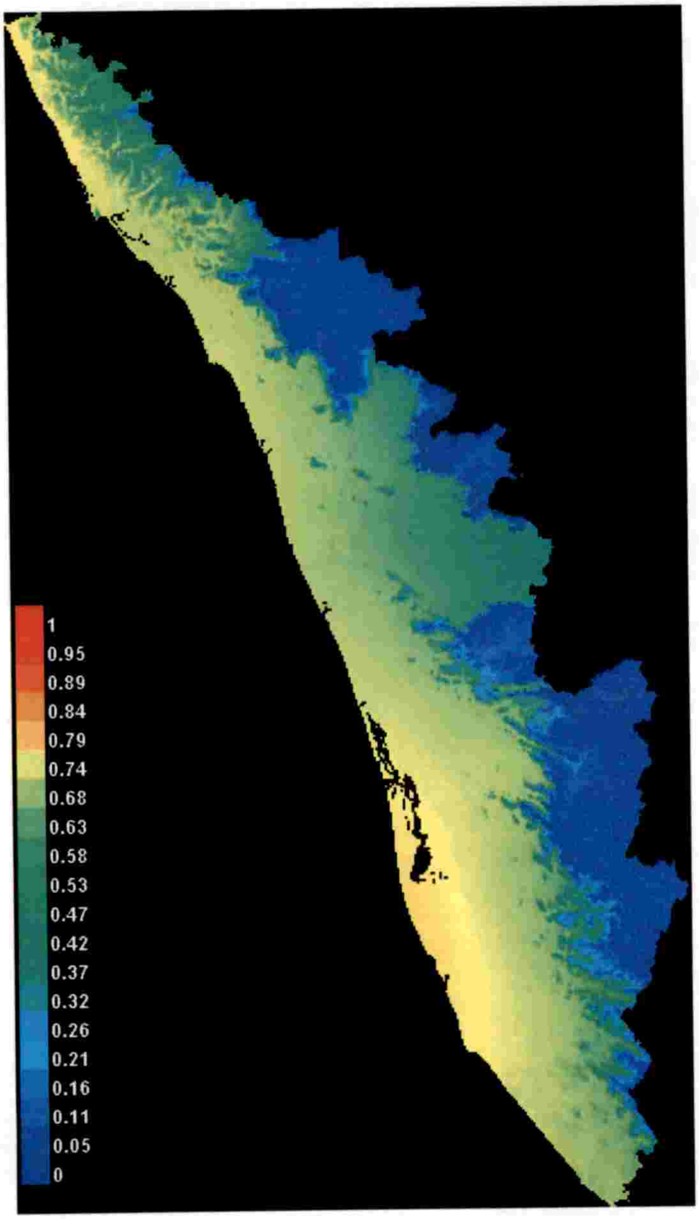

Fig. 77. Prediction of the future distribution of the Isabelline Wheatear for 2050 under RCP2.6 prediction

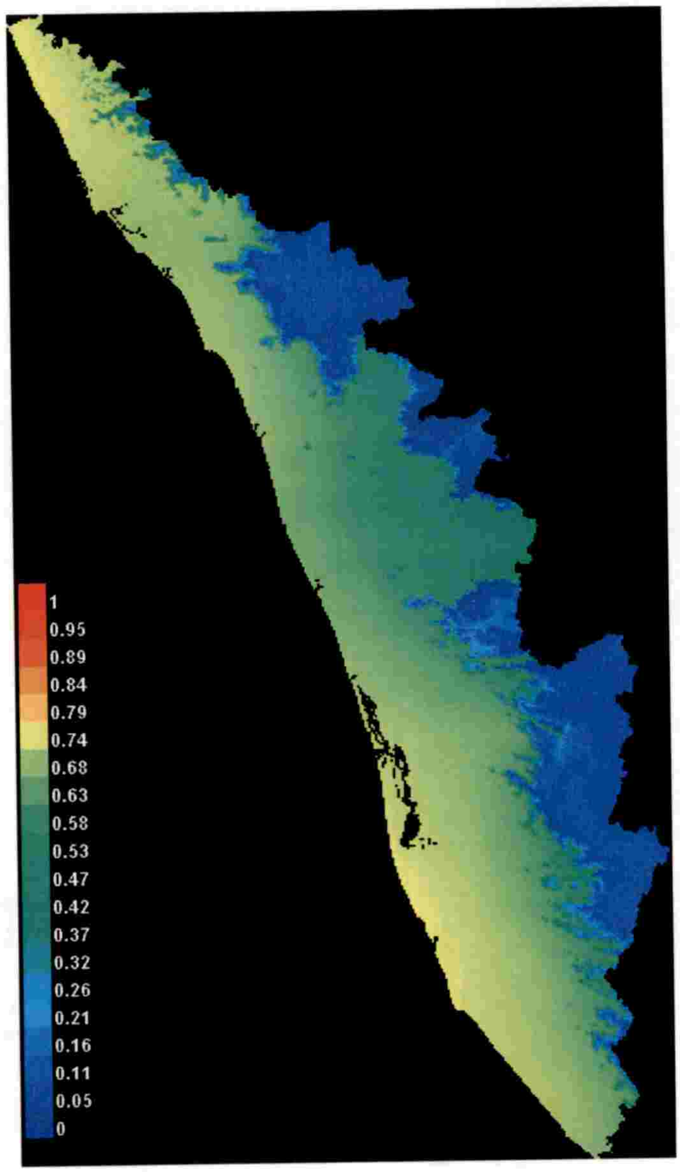

Fig. 78. Prediction of the future distribution of the Isabelline Wheatear in2050 under RCP4.5 prediction

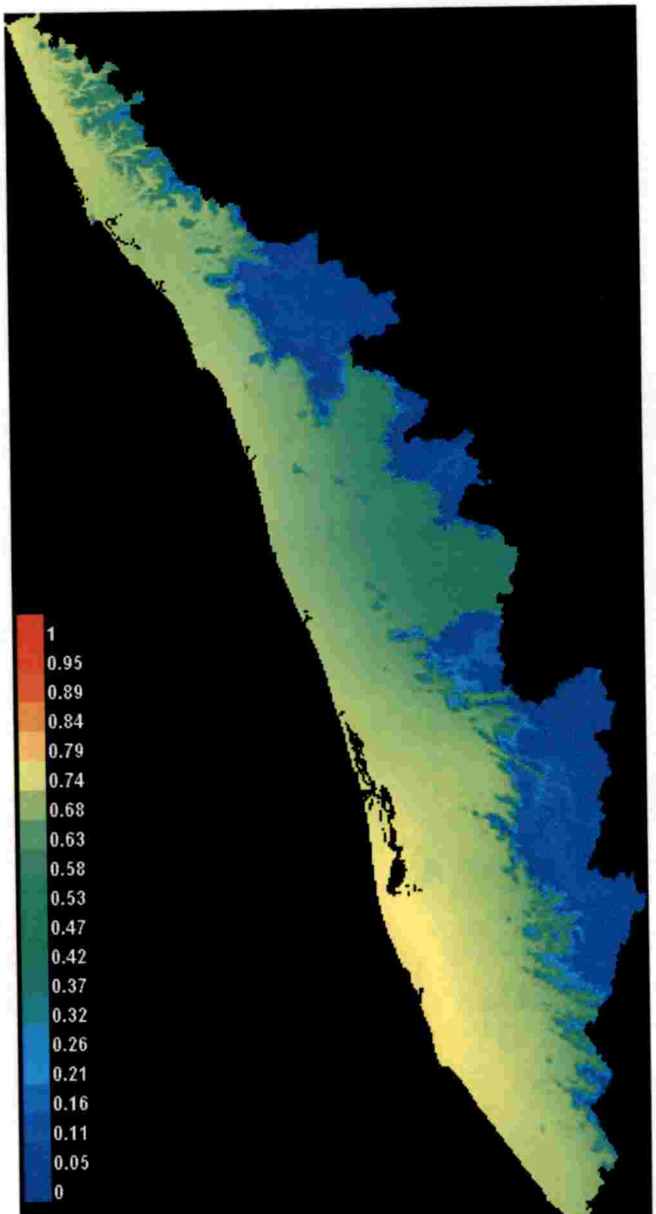

Fig. 79. Prediction of the future distribution of the Isabelline Wheatear in 2050 under RCP6.0 prediction

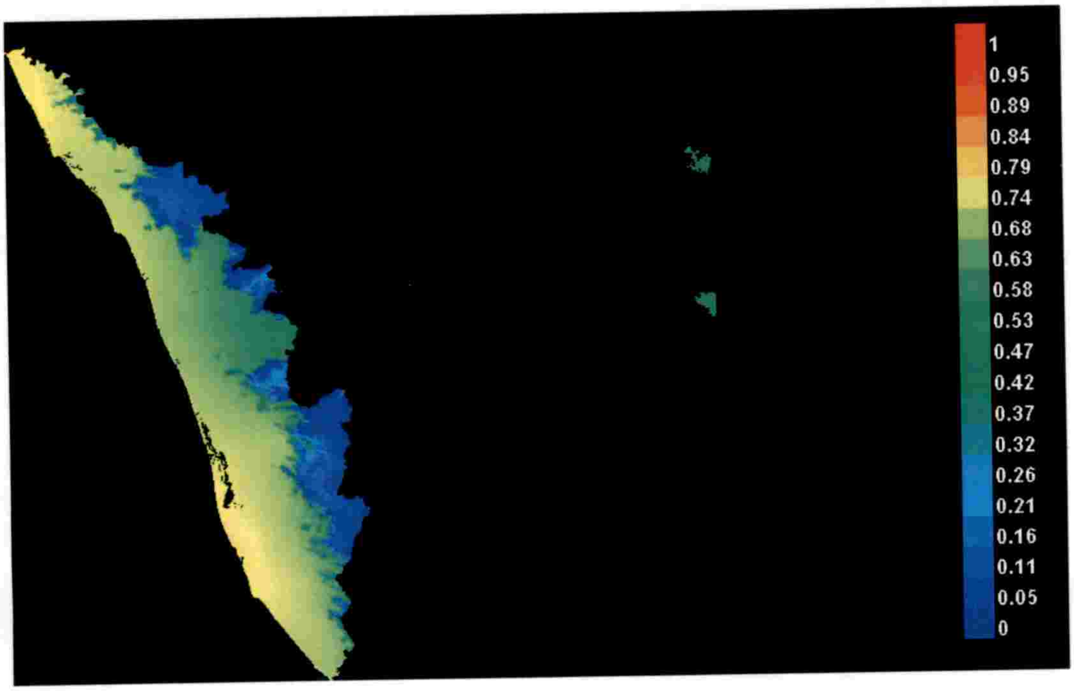

Fig. 80. Prediction of the future distribution of the Isabelline Wheatear in 2050 under RCP8.5 prediction

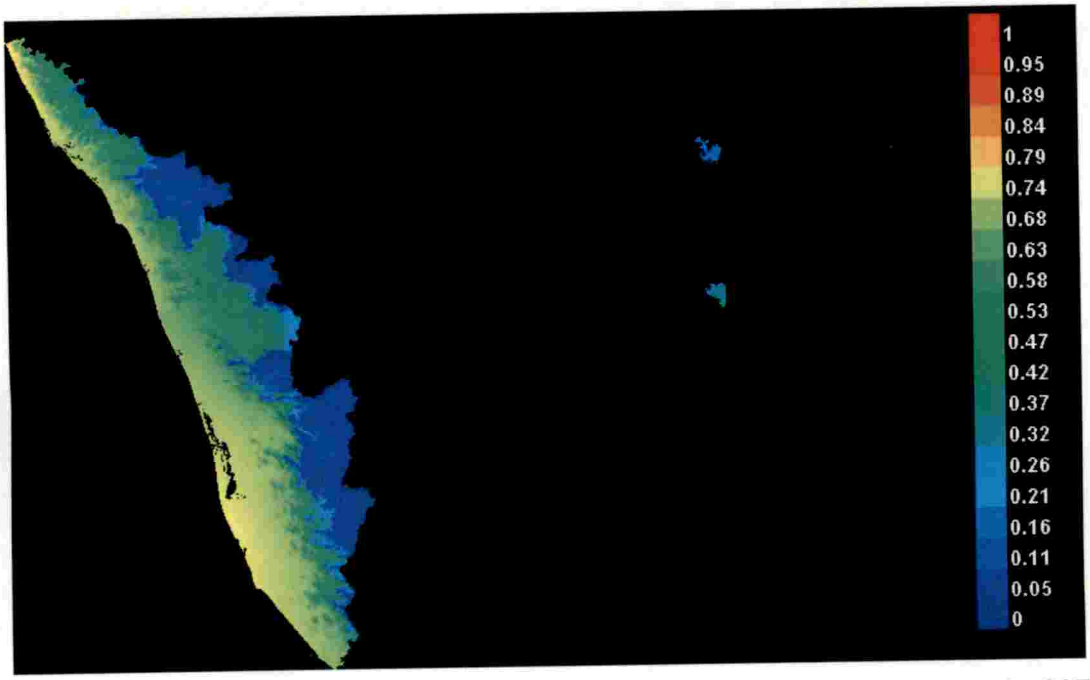

Fig. 81. Prediction of the future distribution of the Isabelline Wheatear in 2070 under RCP2.6 prediction

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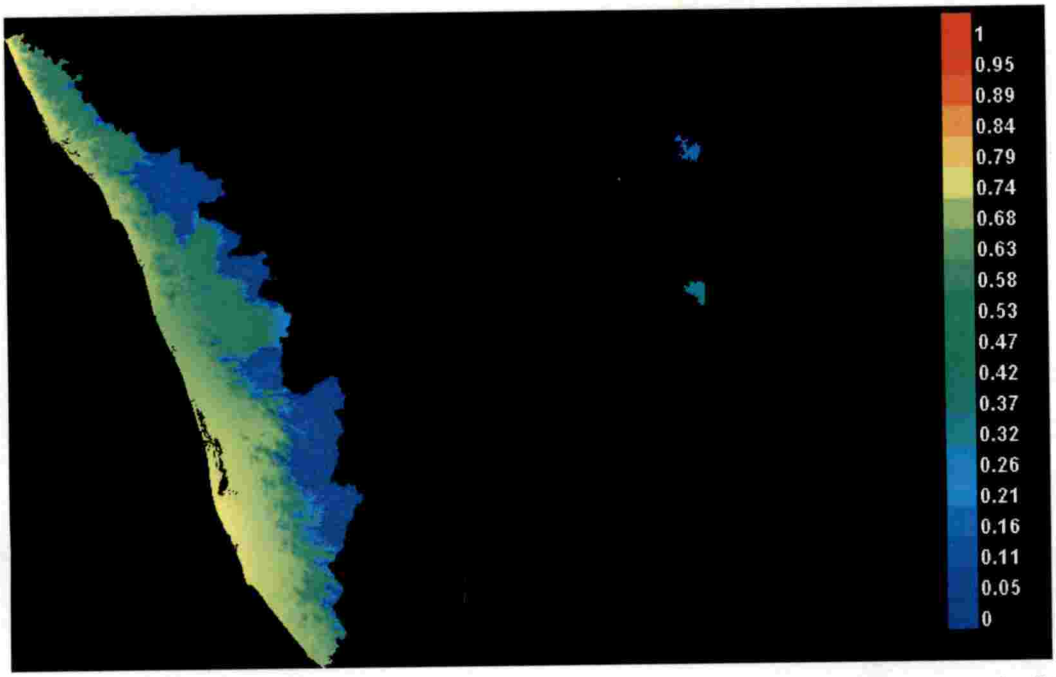
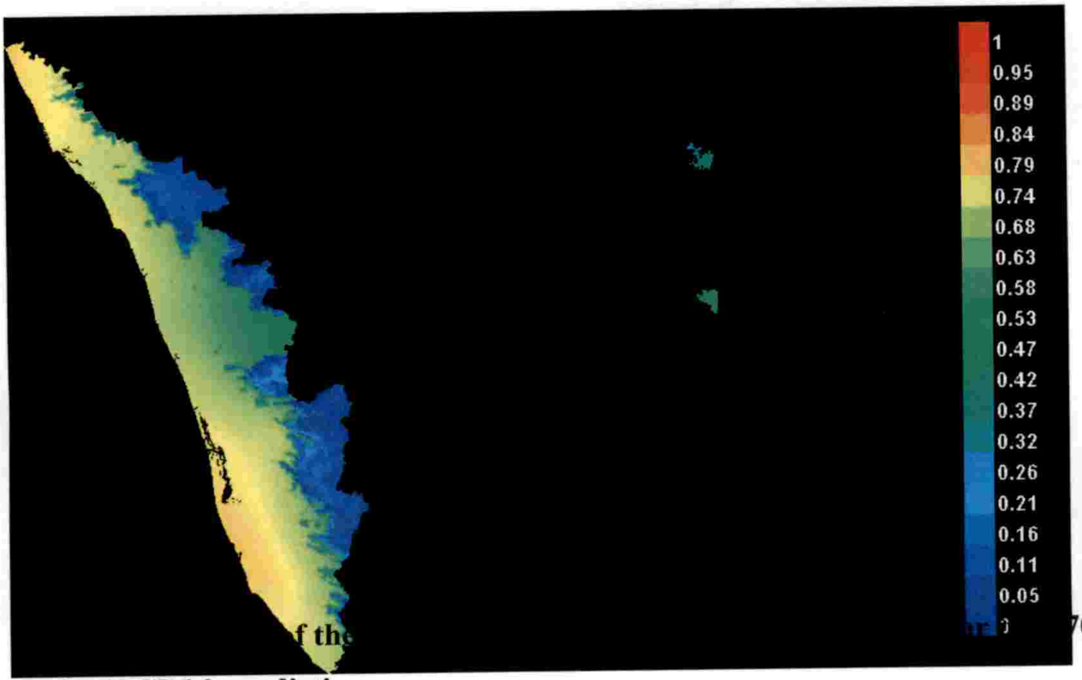


Fig. 82. Prediction of the future distribution of the Isabelline Wheatear in 2070 under RCP4.5 prediction



f th 70
under RCP6.0 prediction

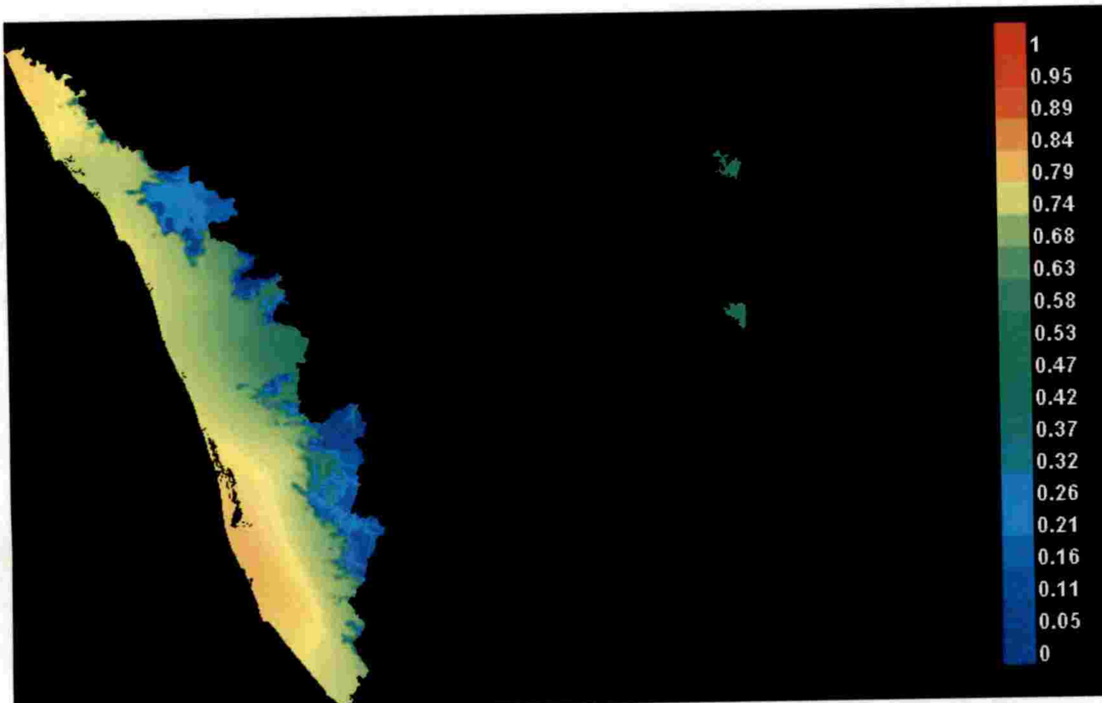


Fig. 84. Prediction of the future distribution of the Isabelline Wheatear in 2070 under RCP8.5 prediction

CHAPTER 5

DISCUSSION

The climate change effect on environment is easily understood from the change in the distribution of species. Extinction of species, habitat fragmentation, and disappearance of intolerant species are the common effects occurring in the environment. Sometimes certain species may be favoured or unfavoured by these climatic effects. Several other species changed their habitat to favourable places or acquire adaptive mechanisms. In order to manage and conserve earth's natural systems, researches are done to identify the environmental drivers that shape species' distributions (Fink *et al.*, 2011). Among the different species, birds are best studied groups due to their sensitivity to small climatic shifts and changes in migration patterns.

The Indian peafowl, sparsely distributed in Kerala is now occurring widespread in the state due to the increase in dryness caused by climate change (Jose, 2016). Likewise, a group of wildlife biologists and bird watchers across the Kerala state have been tracking and identifying atleast 36 species of migratory birds from drier tracts in Kerala for the past 15 years which were not historically reported yet. Some of the identified birds include Bunting species (Black-headed Bunting), Wheatear species (Isabelline Wheatear), Aquila species (Greater-spotted Eagle), Lapwing species (Gray-headed Lapwing), Stonechat species (Common Stonechat) and Bluethroat. At first the sightings were sporadic and then they became more regular, indicating the increased presence of these birds in Kerala.

The current study is based on identifying the present distribution patterns of the selected migratory bird species using 19 bioclimatic factors and the distribution is being projected for the years 2050 and 2070 under four different RCPs viz. RCP2.6, RCP4.5, RCP6.0 and RCP8.5.

Modelling was done by using the MaxEnt software in which the occurrence data points and the climatic parameters are related. The impacts of climate change on the Mountain Pine Beetle under current and future climate scenarios were effectively predicted by MaxEnt modelling techniques in the United States (Dowling, 2015). Similarly in the western United States, three different bark beetles' habitat, including the MPB habitat under current and future climate scenarios was evaluated by using MaxEnt (Evangelista *et al.* 2011).

The point localities of the birds from 1950-2000 were collected from e-Bird database. Fink *et al.* (2011) analyzed e-Bird data to study broad-scale movements of bird populations throughout the year.The climate data is obtained from BioClim. For the current conditions, climate data from 1950-2000 time periods is used. The climate for the years 2050 and 2070 was predicted by using the coupled model HadGEM2-AO of 30 second resolution under four different RCPs.

The results obtained are discussed in this chapter.

5.1 REPLICATION RUN TYPE USED IN THE MODEL

Replication run type is selected to identify the species distribution attributes and to avoid noisy sampling procedures. The most commonly used forms are repeated subsampling and cross-validation. For running the MaxEnt model, in the present study also, cross-validation and subsampling forms of replication are used. According to Merow *et al* (2013), data is used efficiently and statistics is easily done in cross-validation. In cross-validation, the data is utilised for test and train data in order to run the model and obtaining results. Subsampling form of replication provides a stable model (Meinshausen and Buhlmann, 2006; 2010).

Cross-validation works in such a way that the bird's occurrence data is randomly split into a number of folds (equal-sized groups). In turn models are created leaving out each fold, further they are used for evaluation. Cross-validation makes better use of small data sets as it utilises all of the data for validation (Phillips, 2005). In species distribution models, model predictions for sites of presence and absence not fitting the model are computed out to obtain the evaluation statistics for cross-validation procedure (Hijmans, 2012). Subsampling is the most effective replication type used because of lower correlation among variables, has linear consistency (Davison *et al*, 2003). The presence points are repeatedly split into random training and testing subsets in repeated subsampling process (Phillips, 2005).

Here cross-validation was done for birds with less number of datasets and subsampling for the birds with more number of datasets. In the study cross-validation was done for the migratory birds viz. the Black-headed Bunting and the Isabelline Wheatear at different replication numbers of 25, 30, 35 and 40. The remaining birds such as the Bluethroat, the Gray-headed Lapwing, the Stonechat and the Greater-spotted Eagle were modelled by using the subsampling form of replication with test percentages of 10, 15, 25 for

30, 35 replications. For the birds, Isabelline Wheatear and Black-headed Bunting cross-validation type of replication was carried out for different number of replications and the AUC values of 0.604 with SD of 0.193 (Table. 2) and 0.81 with SD of 0.2 (Table. 12) were obtained respectively. Likewise for the Bluethroat an AUC value of 0.891 and SD 0.105 (Table. 4), for the Gray-headed Lapwing an AUC of 0.935 and SD 0.040 (Table. 6), for the Stonechat an AUC value of 0.891 and SD 0.056 (Table. 8) and for the Greater-spotted Eagle an AUC value of 0.896 and SD 0.076 (Table. 10) were obtained after carrying out subsampling form of replication with different number of replications and test percentages.

It is clear from the result that subsampling form of replication is effective and better suited for modelling species distribution since it provided better average AUC value than that obtained from cross-validation type of replication as shown above. The AUC curves of bird species acquired after carrying out subsampling (Fig. 16, Fig. 30, Fig. 44 and Fig. 58) found more reliable than that procured out of cross-validation (Fig. 3 and Fig. 72). Even though cross-validation was selected due to the limited number of presence data, the output received fit comfortable with the model with the AUC values never reached below 0.5. So for modelling species' distribution presence-only data are useful and this information strengthen the need for capitalizing the growing availability of both species' occurrence records (Soberon *et al.* 2000, Graham *et al.* 2004) and high-resolution spatial environmental data. There was much standard deviation but better AUC values obtained in each model made the result more meaningful. AUC has been used extensively in the species' distribution modelling literature. It represents the capacity of a model to separate between the locations where a species is found, versus those where it is not found (Lobo *et al.*, 2008).

5.2 VARIABLE CONTRIBUTION TO THE MODEL OF THE SELECTED MIGRATORY BIRD SPECIES

Environmental constraints will lead to change in the climatic conditions directly affecting the species distribution and the corresponding species responses are measured by niche models like MaxEnt (Sharma, 2014). Among the 13 bioclimatic variables used, which environmental variables are making the greatest contribution to the model are able to be tracked while training the MaxEnt model. By improving the coefficient for a single character, the steps undertaken by the MaxEnt algorithm increases the gain of the model. The program assigns the increase in the gain to the environmental variable(s) that the character depends on. Then at the end of the training process, the gain is converted to percentages and hence percent contribution of the variable is obtained (Phillips, 2005). As per Srivastava (2013) considerable environmental conditions and niches favorable or unfavorable for species over large geographic regions have been established by the ecologists with the availability of fine resolution environmental variables and advancements in species distribution models based on presence and absence data. According to Jose (2016) for the construction of the MaxEnt model of the Indian Peafowl the percentage contribution by the variable, temperature seasonality (bio4) was the highest (28%) whereas mean temperature of driest quarter (bio9) hardly contributed the model.

From the table. 2 it is clear that in the modelling of the Black-headed Bunting the mean diurnal temperature (bio2) showed higher percent contribution. Other than bio2, the minimum temperature of the coldest month (bio6) benefitted the model in the distribution of the Black-headed Bunting. A contribution of 38.2% was done by bio2 and that of bio6 was 26.8%. The table.5 reveals that the minimum temperature of the coldest month (bio6) shown a higher percent contribution of 49.7 and the mean temperature of the driest quarter (bio9) shown a percent contribution of 26.5 in the case of the Bluethroat. Other eight variables contributed less than 10. Among the bioclimatic variables used in the modelling of the Gray-headed Lapwing, the minimum temperature of the coldest month (bio6) showed high percent contribution of 70 and about 13 other variables had a percent contribution less than 10 and that of variables bio10, bio12, bio5, bio13, and bio18 was negligible. Next to bio6 was the mean temperature of the driest quarter (bio9) and the temperature annual range (bio7) with decreased percentages of 6.8 and 6.6 respectively (Table. 7). For the Stonechat species the precipitation of the driest quarter (bio17) showed high percent contribution of 30.5 (Table. 9) followed by the minimum temperature of the coldest month (bio6) and the precipitation of the driest quarter (bio19) with percent values of 21 and 17.8 respectively. Remaining variables had a percent contribution only less than 10. The mean temperature of the coldest month (bio6) showed a high percent contribution of 45 to the model for the Greater-spotted Eagle. The variable, precipitation of the driest quarter (bio19) showed a percent value of 15 and only less than 10 by the other variables (Table. 11). In the case of the Isabelline Wheatear, the mean temperature of the coldest month (bio6) showed a high percent contribution of about 70.7. The variables bio2, bio12, bio7, bio1, bio3 and bio9 showed a percent value less than 10 and negligible contribution by the remaining variables. The models for all the bird species had a common contribution from the variable, the minimum temperature of the coldest month (bio6). For the Gray-headed Lapwing and the Isabelline Wheatear, bio6 had given the greater contribution and it was less for the Stonechat species and the Black-headed Bunting. On the other hand for the Black-headed Bunting and the Stonechat species, major percent contribution was given by the variables bio2 and bio17 respectively. The percent contribution values are only heuristically defined. These path dependent values were obtained according to the Maxent code, used to reach the optimal solution, such that a different algorithm in MaxEnt could give the same solution via a different path, resulting in different percent contribution values.

Permutation importance is a path-independent measure and depends only on the final MaxEnt model. Random permutation is done for analysing the contribution of each variable by using the values of that variable with the presence and background training points. Then the resulting decrease in AUC is measured. Larger decrease in AUC indicates heavier dependence of the model on that variable. These values are finally normalized to give percentages (Phillips, 2005). For the distribution of model for the Indian Peafowl, the precipitation of driest month (bio14) showed higher importance followed by the precipitation of wettest month (bio13), precipitation of driest quarter (bio17), precipitation of warmest quarter (bio18) and temperature seasonality(bio4) (Jose, 2016). Mean diurnal range of temperature (bio2) and mean temperature of warmest quarter (bio9) showed more importance with 38.6 and 35.8 percent respectively in the case of permutation for the distribution of the model for the Black-headed Bunting (Table. 3). The variables like mean temperature of coldest quarter (bio11), annual mean temperature (bio1), precipitation of warmest quarter (bio18), precipitation seasonality (bio15) and maximum temperature of the warmest month (bio5) showed a permutation importance less than 10.For the Bluethroat, the permutation importance shown by bio6 was 51.3 and that of the annual mean temperature (bio1) and the precipitation seasonality (bio15) was greater than 10 (Table. 5). In the case of Gray-headed Lapwing, the permutation importance given by the mean temperature of the coldest month (bio6) was the greatest (49.3), next to that was mean temperature of wettest quarter (bio8) with a value of 24.1. Nine of the other variables showed a value less than 10 (Table. 7). The permutation importance (Table. 9) showed by the precipitation seasonality (bio15) was the greatest (24.3) for the Stonechat species. Next to that was the mean diurnal range (bio2) with a value of 20.7 followed by the annual precipitation (bio12) (11.6) and the precipitation of the driest quarter (bio17) (10.2). From the table. 11, it is seen that the value of permutation importance by the minimum temperature of coldest month (bio6) for the model of the Greater-spotted Eagle was 25.1 while that for the precipitation seasonality (bio15) and the mean diurnal range (bio2) were 17.3 and 15.7 respectively. For the model for Isabelline Wheatear, the permutation importance by the minimum temperature of the coldest month (bio6) was 50.3, next to that were the variables, mean diurnal range (bio2) and annual mean temperature (bio1) with values 24.7 and 11.2 respectively. For the other variables permutation importance was negligible.

While comparing the permutation importance and percent contribution in MaxEnt output for analyzing the results, the former one should be the better choice than the later one as the later one is based on the way variables are ordered in the model but the former is the updated one. But here except for the Black-headed Bunting and the Stonechat species, all other species have the highest percent contribution and permutation importance from the variable bio6 itself. The percent contribution from bio2 was greater than that from bio6 in the model for the Black-headed Bunting. Considering the permutation importance also bio2 has the highest value. Similarly for the Stonechat species highest percent contribution was from bio17 than bio6. But the permutation importance by bio15 was much greater than bio 17. Anyway the measurement of contribution of each variable will be more useful. For that purpose the jack-knife test is helpful and alternate estimation of variables will be done.

A jack-knife procedure is useful in identifying which variables contribute the most individually. The relative importance of each predictor variable is evaluated and accurately predicts the new ranges in the model. In jack-knife analysis the training gain of each variable when the model was run in isolation is calculated and compared with the training gain with all the variables (Srivastava, 2013). Temperature annual range (bio7) and temperature seasonality (bio4) showed good fit to the training data and provided the useful information by itself in the model for the Indian Peafowl (Jose, 2016). The results of the jack-knife test of variable importance for the Black-headed Bunting shown in Fig.5. tell that the environmental variable with highest gain when used in isolation is the mean diurnal range (bio2), which therefore appears to have the most useful information by itself followed by the minimum temperature of the coldest month (bio6) and that decreases the gain the most when it is omitted is also bio2, which therefore appears to have the most information that isn't present in the other variables. For the Bluethroat, the environmental variable with highest gain when used in isolation is bio6 and also that decreases the gain the most when it is omitted is bio6. The variables annual mean temperature (bio1) and mean temperature of driest quarter (bio9) lies very next to bio6 while considering the gain (Fig. 19). The environmental variable, minimum temperature of coldest month (bio6) shows highest gain when used in isolation and decreases the gain the most when it is omitted, in the model for the Gray-headed Lapwing

(Fig. 33). The variables mean diurnal range (bio2) and temperature annual range (bio7) increase the gain other than bio6. For the Stonechat species, the jack knife test of variable importance shown in Fig. 47. tell that the environmental variable with highest gain when used in isolation is the mean diurnal range (bio2), which therefore appears to have the most useful information by itself. The precipitation of the driest quarter (bio17) stands next to bio6 considering the gain to the model. The environmental variable that decreases the gain the most when it is omitted is bio17, which therefore appears to have the most information that isn't present in the other variables. The results of the jack-knife test of variable importance for the Greater-spotted Eagle shown in Fig. 61. revealed that the minimum temperature of coldest month (bio6) showed the highest gain when used in isolation and decreased the gain the most when omitted. For the distribution of model of Isabelline Wheatear also the environmental variable, minimum temperature of coldest month (bio6) shows the increase in gain when used in isolation and the most decrease in gain when omitted.

Analysing the percent contribution, permutation importance and jack-knife test for the model of the given bird species it is evident that the variable bio6 has an indispensable role in the distribution of the selected migratory birds considered in the study. Along with that bio2 and bio17 play a significant role in the distribution of the Black-headed Bunting and the Stonechat species respectively.

One type of the response curves from the MaxEnt output are the curves with logistic prediction changes as each environmental variable has varied, keeping all other environmental variables at their average sample value. Positive responses were shown by the variables annual mean temperature (bio1), mean temperature of driest quarter (bio9), mean temperature of coldest quarter (bio11) and precipitation of warmest quarter (bio18) compared to the moderate responses by isothermality (bio3), temperature seasonality (bio4), maximum temperature of warmest month (bio5), minimum temperature of coldest month (bio6), temperature annual range (bio7), mean temperature of wettest quarter (bio8), mean temperature of warmest quarter (bio10), annual precipitation (bio12), precipitation of wettest month (bio13), precipitation of driest month (bio14), precipitation of wettest quarter (bio16), precipitation of driest quarter (bio17) and precipitation of coldest quarter (bio19) for the model of the Black-headed Bunting. The variables like precipitation of warmest quarter (bio18) and mean diurnal range (bio2) shown less significance to the survival of species. The response curves for the Bluethroat (fig. 17) show that annual mean temperature (bio1), minimum temperature of coldest month (bio6), mean temperature of driest quarter (bio9) and precipitation seasonality (bio15) have positive effect on its distribution. Remaining all other variables showed less significance below 50 percent probability. The variables (fig. 31) minimum temperature of coldest month (bio6), mean temperature of driest quarter (bio9), precipitation seasonality (bio15) and precipitation of wettest quarter (bio16) show positive response compared to the moderate responses by annual mean temperature (bio1), temperature seasonality (bio4), maximum temperature of warmest month (bio5), temperature annual range (bio7), mean temperature of warmest quarter (bio10), mean temperature of coldest quarter (bio11), annual precipitation (bio12), precipitation of wettest month(bio13), precipitation of driest month (bio14), precipitation of warmest quarter (bio18) and precipitation of coldest quarter (bio19) in the case of Gray-headed Lapwing. Some variables like precipitation of driest quarter (bio17), isothermality (bio3) and mean diurnal range (bio2) showed less significance to the survival of species. For the modelling of the distribution of the Stonechat species, greater responses were shown by the minimum temperature of coldest month (bio6), temperature annual range (bio7), mean temperature of driest quarter (bio9), precipitation of coldest month (bio14) and precipitation seasonality (bio15) (fig.45). The variables annual mean temperature (bio1), mean diurnal range (bio2), annual precipitation (bio12), precipitation of driest quarter (bio17) and precipitation of coldest quarter (bio19) showed moderate response to species distribution. Below 50 percent probability was observed for the remaining variables with regard to the distribution of birds. As shown in fig. 59. for the modelling of the Greater-spotted Eagle, positive effects were displayed by the variables annual mean temperature (bio1), minimum temperature of coldest month (bio6), mean temperature of driest quarter (bio9) and precipitation of driest month (bio14). The variables precipitation of warmest quarter (bio18) and precipitation of coldest quarter (bio19) showed moderate response to species distribution. Moderate responses were shown by mean diurnal range (bio2), isothermality (bio3), temperature seasonality (bio4), maximum temperature of warmest month (bio5), temperature annual range(bio7), mean temperature of wettest quarter (bio8), mean temperature of warmest quarter (bio10), mean temperature of coldest quarter (bio11), annual precipitation (bio12), precipitation of wettest month (bio13),precipitation of driest month (bio14), precipitation seasonality (bio15), precipitation of wettest quarter (bio16) and precipitation of driest quarter (bio17). The response curves from the MaxEnt output for the Isabelline Wheatear (fig. 73) shown that the variables annual mean temperature (bio1), minimum temperature of coldest month (bio6), mean temperature of driest quarter (bio9) and annual precipitation (bio12) responded positively. In the case of other variables, they showed moderate response to the presence of the migratory bird.

Eventhough change in a single variable is reflected in these curves, as a whole the model may utilise the condition of sets of variables changing together.

Another set of response curves from the MaxEnt output showed the change in predicted probability when the corresponding variable is only used. Figures (4, 18, 32, 45, 60 and 74) represents the response curves of each variable in the distribution of the Black-headed Bunting, the Bluethroat, the Gray-headed Lapwing, the Stonechat species, the Greater-spotted Eagle and the Isabelline Wheatear respectively, created using only the corresponding variable.

In the case of the Black-headed Bunting, when the annual mean temperature (bio1) was between 28°C-29°C, the probability of occurrence was 60%. The presence of the bird was sure with 80% probability when the mean diurnal range was 5.5°C-6°C. The occurrence rate decreased as the value of mean diurnal range (bio2) increased above 9.5°C. There was 50% probability for the occurrence of the bunting when isothermality (bio3) ranged from 5.5-7.1. Between 7.5°C-8.5°C of temperature seasonality (bio4) the distribution of the species was high with a probability of 0.55. The distribution range became negative with the increase in bio4. When the maximum temperature of warmest month (bio5) reached 33°C the probability of occurrence was 50%. Then the probability increased to 0.57 between 37°C-39°C of bio5. The probability of occurrence of the Black-headed Bunting was 0.6 as the minimum temperature of coldest month (bio6) increased from 14°C-23°C. Between temperature ranges of 23°C-24°C, the chance was consistent. Between 8°C-9°C temperature annual range (bio7) the presence of the Black-headed Bunting was high with more than 70% possibility. The value decreased and reached to a minimum at 15.5°C-16.2°C. The presence of the bird was noted with a probability greater than 80% as the mean temperature of wettest quarter (bio8) varied from 28°C-30°C. Between 29°C-31°C of the mean temperature of driest quarter (bio9) the presence of the bird was observed with a probability of 0.7. The probability decreased below 50% as bio8 lowered beyond 27°C. The probability of occurrence was above 60% (consistent) when the mean temperature of warmest quarter (bio10) varied between 30°C-32°C. Below 29°C the possibility of presence decreased. A maximum stable probability (0.65) was observed when the mean temperature of coldest quarter (bio11) ranged between 26.8°C-28.2°C. The likelihood of existence of the bird was found above 55% when the annual precipitation (bio12) was around 7000mm. When bio12 was between 3000mm-6000mm the chance was 50-55%. When the precipitation of wettest month (bio13) was in the range of 1500-2500mm the likelihood of appearance of the bird was the maximum (0.58).

When the precipitation of driest quarter (bio14) increased to 40mm the probability of occurrence of the bird decreased below 50%. For negligible value of the precipitation of driest quarter (bio14) the bird's appearance was observed with 51% probability. The existence with 50% probability was observed above 105mm of precipitation seasonality (bio15). The probability increased above 55% when bio15 was between 130mm-140mm. Between >2500mm and <5000mm of the precipitation of wettest quarter (bio16) the probability of existence of the bird was above 0.5. With a value of 0.58 the probability range was consistent between 5000mm-5500mm of bio16. The possibility of appearance was 0.55 when the precipitation of driest quarter (bio17) was negligible. Later the probability range decreased with increase in bio17 to 160mm, between 50mm and 350mm there was favourable probability for bird's existence with a value ranging between 0.5-0.56. The possibility range decreased when the precipitation of warmest quarter (bio18) was >400mm and <1000mm. The likelihood of occurrence was greater than 50% for the value of bio19 >500mm and <4500mm. The chance was 0.56 when the precipitation of coldest quarter (bio19) varied between 4000mm-4500mm.

The likelihood of distribution of the Bluethroat was greater (0.69) when the annual mean temperature (bio1) was 27.5°C. Above 28°C, approaching to 30°C the probability was 49%. The presence rate also decreased below 27°C. The highest probability (0.61) was observed between 5.5°C-6°C mean diurnal range (bio2). Later at 7°C the chance decreased to 55% and at 7.5°C the possibility again reduced to 50%. When bio2 was >7.5°C and <10°C the chance of occurrence was minimum. The favourable likelihood of occurrence (0.55) was observed when isothermality (bio3) reported as 6.35. Except between the isothermality range of 6.2-6.6 the likelihood of appearance was below 50%. Between 12°C-12.5°C of temperature seasonality (bio4) the probability of occurrence was higher (0.52). The possibility was 50°C when bio4 ranged between 11°C-17.5°C. When the value of the maximum temperature of warmest month (bio5) was between 33°C-39°C the chance of occurrence became greater than 50%. The possibility was the maximum(0.6) at34°C of minimum temperature of the coldest month (bio6). The favourable temperature for the occurrence of the bird was between 22°C-24°C. At 22.5°C the probability was 70% and between 23°C-24.1°Cthe chance became consistent (60%). In the case of temperature annual range (bio7), 50% probability was found between 8.5°C-12.1°C. But the maximum possibility (0.55) was observed at 10.2°C. With the increase in bio7 to 14°C probability decreased to 0.25 and then increased to 0.3 as bio7 rose to 16°C. The maximum possibility

(55%) of occurrence of the bird was found at 26.1°C of mean temperature of wettest quarter (bio8) further at 27°C the probability reduced to 50%. Again the chance much lowered to 28°C. The likelihood of occurrence (0.32) remained consistent when bio8 ranged between 28°C-30°C. For the Bluethroat 80% probability of occurrence (consistent) was observed when the value of mean temperature of driest quarter (bio9) was between 29°C-31°C. Above 28°C of bio9 the chance of existence was 50%. When bio9 >29°C and <30.2°C there was 50% and above possibility of appearance of the bird. At 29.5°C maximum possibility (0.6) was found. The value went below 0.5 and remained consistent between 30°C and 32°C. The favourable occurrence was found at 26.1°C of mean temperature of coldest quarter (bio11) with a chance of 58%. The probability of occurrence lowered to 40% as bio11 increased above 28°C. When the annual precipitation (bio12) was 3000mm the possibility of appearance was higher (0.57). With the increase in bio12 from 3000mm-7000mm the probability rate decreased to 30%. Between 500mm and 1000mm of the precipitation of wettest month (bio13) the maximum probability (0.59) was observed at 550mm. The precipitation >1000mm and <2500mm was less favourable for the appearance of the bird. When the precipitation of driest month (bio14) was less than 5mm (especially around 2mm) the likelihood of existence of the bird became 68%. The chance decreased to 0.35 as the precipitation increased above 5mm and remained consistent till 40mm. The possibility of presence (60%) was observed maximum at 100mm precipitation seasonality (bio15). Between 50mm-100mm of bio15 the chance of appearance had increased and after 100mm the possibility decreased and remained stable until 140mm. When the precipitation of wettest quarter (bio16) reached near 2000mm the possibility of occurrence was 0.58 (maximum). As bio16 increased to 3000mm the probability became 50%. The chance of occurrence decreased (35%) with increase in bio16 to 5000mm. The likelihood of occurrence increased to 0.57 as the precipitation of driest quarter (bio17) became 40mm. With the decrease in bio17 to 115mm and then greater than 140mm the probability of occurrence reduced. There was greater than 50% chance of existence of the Bluethroat when the value of the precipitation of warmest quarter (bio18) ranged between 350mm-1000mm. The precipitation below 300mm was not favourable for the bird's occurrence. The possibility was higher (0.52) when bio18 was 400mm. With 60% chance of occurrence the precipitation of coldest quarter (bio19) at 1900mm was favourable for the bird. The probability decreased to 50% as the precipitation value became 2500mm and further decreased to 25% at 4500mm. At below 1500mm the condition was not favourable for the occurrence of the Bluethroat.

When the annual mean temperature (bio1) was between 27°C and 28°C the probability of presence of the Gray-headed Lapwing was 0.5. At 27.5°C the probability was the maximum (60%). The probability decreased with increased bio1 up to 30°C.When the mean diurnal range (bio2) was between 5.5°C and 6.3°C the chance of occurrence was greater and remained stable. The possibility decreased to 50% at 6.1°C and further decrease was observed with increase in bio2. When isothermality (bio3) was between 6.4 and 7 the likelihood of existence was greater than 50%. The probability became a stable higher value (70%) when bio3 ranged from 6.9-7.1. Isothermality below 6.4 was not favourable for the appearance of the bird. The possibility of presence was more than 50 percent when 7.5°C> bio4<10°C. The value of probability was 69% when temperature seasonality (bio4) ranged between 7.5°C-8.5°C. The possibility decreased (40%) with increase in bio4 from10°C-13°C and further decreased as bio4 went high (17°C). A favourable chance of occurrence was found between 33°C-35°C of maximum temperature of warmest month (bio5). Beyond 35°C of bio5 the possibility lowered. A 62% chance was observed at 34°C of bio5. The likelihood of existence increased from 0.1-0.92 with the increase of the minimum temperature of coldest month (bio6) from 21.9°C-22.8°C. At 22.8°C the existence was highly favourable and the chance remained stable up to 24.1°C. The likelihood of occurrence was greater (91%) when temperature annual range (bio7) was 8°C-9°C. As bio7 increased from 9°C-9.5°C, the probability reduced to 50%. Further the chance of occurrence decreased for increase of bio7 from 10°C-16°C. The chance of occurrence was fair above 26°C of the mean temperature of wettest quarter (bio8). When bio8 ranged between 28°C-30°C, 63% stable possibility was found. For the appearance of the bird the mean temperature of driest quarter (bio9) ranged between 27°C°C-29°C with 50% probability. The maximum possibility (61%) was shown when bio9 reached 28.1°C. A stable decreased chance (40%) was found at a temperature range of 29°C-31°C. When the mean temperature of warmest quarter (bio10) was between 28°C and 30°C there would be probability for bird's presence. Highest possibility (62%) was observed at 29°C. Beyond 29°C the chance decreased and became the lowest in between 30°C and 32°C. Better likelihood of appearance was seen at 26.2°C of the mean temperature of coldest month (bio11) with a value of 60%. From24°C-26°C of bio11 probability increased to 50%. The temperature increment from 26.2°C-28°C showed decrease in chance of occurrence to 25%. Between 500mm-1000mm of annual precipitation (bio12), the possibility of occurrence was stable and good. Then at 2200mm the chance loweredand with 3000mm bio12 63% probability was there for bird's distribution. After 3500mm the chance reduced till 7000mm. When the precipitation of wettest month (bio13) was 700mm there observed maximum probability (58%). Below 500mm and beyond 1000mm the chance was less. The favourable condition for existence of the species was observed when precipitation of driest month (bio14) varied between 10mm and 25mm, beyond 25mm the possibility of appearance decreased. Between 70mm-105mm precipitation seasonality (bio15) the probability was above 0.5. Around 10mm of bio15 the possibility increased to 55% and then sudden decline was observed as precipitation rose to 140mm. Other than between 1500mm and 2500mm of the precipitation of wettest quarter (bio16) the chance of existence of the bird was below 50%. Highest probability (60%) was observed when bio16 was around 2000mm. Considering the precipitation of driest quarter (bio17) between 35mm and 120mm the probability was greater than 50%. With 0.57 stable chance of occurrence bio17 range of 40mm-90mm was preferable. The decline in bio17 from 119mm to 160mm showed decline in probability. As the precipitation of warmest quarter (bio18) increased, the likelihood of appearance also increased and remained stable (50%) from 400mm-700mm. A probability of 0.56 and 0.6 were shown when bio18 measured 400mm and 550mm respectively. Increase ofbio18 from700mm to around 1000mm showed less favourable condition for the occurrence of the bird. The value of the precipitation of coldest quarter (bio19) ranging from 1000mm-2000mm found good for the survival of the species. At 1250mm the probability was 55% and around 2000mm the highest probability (0.57) was analysed. The probability later on decreased continuously up to 4500mm.

The probability of occurrence of the Stonechat increased with increment in annual mean temperature above 26°C. A 50 percent chance was observed in between 27°C-28°C. Highest probability (58%) was observed at 27.5°C. Thereafter probability decreased with the increment in bio1 to 30°C. The response curve for the mean diurnal range (bio2) showed a decreasing and increasing trend. Between 5.5°C-6°C of bio2 70 percent was the likelihood of appearance. After that the trend suddenly declined when bio2 was in the range of 6°C-6.5°C. Again possibility rose above 70% beyond 7°C and declined when temperature increased from 8°C-8.5°C. Finally the chance increased above 70 percent and remained stable as bio2 ranged between 9.5°C-10°C. The isothermality (bio 3) value of 6.25 showed 60% probability for bird's occurrence. A sudden decrease was observed as bio3 increased to 6.5. Meanwhile beyond 6.6 value of isothermality the chance of presence of the bird had an increment more than 50% and showed the highest stable value (0.77) for 6.9 to >7. Fair chance (55%) of existence of the bird was found at 11.5°C temperature seasonality (bio4). Thereafter probability decreased till 15°C of bio4. Above 15°C the possibility again expanded to a higher value of 78% (consistent) from 16.4°C-17.2°C of bio4. At 33°C of the maximum temperature of warmest month (bio5) the chance of occurrence was much better (60%). The existence probability decreased as bio5 rose to 36°C. Thereafter a steady increase in presence was noted and between 37°C-39°C the likelihood of appearance became 70%. The minimum temperature of coldest month (bio6) was found to be favourable for bird's occurrence above 22°C. Between 22.9°C-24.1°C the chance was highest (65%). With a probability of 0.65 at 8°C-9°C temperature annual range (bio7) the presence of the Stonechat was observed. Increase in bio7 to 9.5°C caused the lowering of the probability. Between 10°C-11.5°C occurrence was reported with a stable 60 percent probability. Again the chance decreased with increase in bio7 from 12°C-14°C. Thereafter probability continuously increased and the highest stable value (81%) was obtained between 15.5°C-16.5 of bio7. As the mean temperature of wettest quarter (bio8) increased the probability of occurrence also increased and a fair chance was observed from 25°C-27°C. At 26.1°C the probability was the maximum (60%). For a temperature beyond 27°C of the mean temperature of driest quarter (bio9) there was 50 percent likelihood of appearance of the bird. Between 27°C-28°C a 50 percent stable possibility was found. Thereafter probability increased to a greater consistent value (67%) between 29°C-31°C of bio9. In the case of the mean temperature of warmest quarter (bio10) the chance of existence was above 50% around 29°C. At 29°C the probability became 0.6. After that a sudden decline in temperature occurred at 30°C. But there was a simultaneous increase in possibility just beyond 30°C. The likelihood was found to be 68%, a stable value from 30.2°C-31.8°C of bio10. There was a steady increase and decrease in probability between 25°C-27°C of the mean precipitation of coldest quarter (bio11). At 26.2°C the chance of appearance was highest (61%). The probability decrease showed a stable value between 26.9°C-28.2°C of bio11. With a consistent probability of 0.36 the existence of the bird was observed between 500mm-1000mm, afterwards till 2000mm the chance decreased and beyond 2000mm there was a sudden increase. The maximum value (0.68) of likelihood of appearance was found at an annual precipitation (bio12) of 3500mm. Later the chance decreased with increase in precipitation. From around 500mm of the precipitation of wettest month (bio13) the probability of occurrence increased and reached the maximum value (0.75) beyond 1000mm. Thereafter the chance of existence decreased steadily when the precipitation increased above 1500mm. When the precipitation of driest month (bio14) was 3mm, the existence of the bird was higher (70%). Below 5mm a steady increase and decrease in probability was observed. Beyond 5mm the likelihood showed a consistent value (35%) till 25mm. The possibility of occurrence decreased continuously with increase in bio14 to 40mm. In between 50mm-80mm precipitation seasonality (bio15) the value of probability increased to 40%. From 80mm-117mm the chance became 0.45 and remained stable. Beyond 117mm a steady increase in possibility occurred with a maximum value at 122mm. Thereafter the chance steadily declined with increase in bio15 from 125mm-140mm. The maximum possibility of appearance was found to be at 2500mm of the precipitation of wettest quarter (bio16). Between 100mm-2500mm a steady increment in probability was noted. The precipitation between 2500mm-5500mm showed a corresponding decline in the distribution of the species. The precipitation between 1700mm and 3000mm had only showed likelihood above 50%. When the precipitation of driest quarter (bio17) exhibited 15mm the chance of existence of the bird was greater. Between 2mm-15mm the probability greatly increased and from 15-19mm the chance declined. From 20mm-100mm of bio17 the probability decreased to a stable 30%. But beyond 100mm the possibility rose to 40% and finally decreased down as bio17 incremented than 140mm. Beyond 100mm of the precipitation of warmest quarter (bio18) the probability of occurrence of the bird increased. At 300mm a maximum of 55 percent was the possibility of existence and afterwards till 370mm the chance decreased. Later at 560mm slight increase in probability was observed. Beyond 600mm the chance of occurrence steadily decreased for increased rate of precipitation. Starting from 250mm of the precipitation of coldest quarter (bio19) continuous increment in the probability was observed. At 2000mm possibility was the maximum. Beyond 2000mm the likelihood of appearance decreased with increase in bio19.

When the annual mean temperature (bio1) was between 26°C-28°C the distribution of the Greater-spotted Eagle was greater. Within this temperature range an increasing and decreasing trend was exhibited. At 27.5°C the possibility of presence of the bird was the maximum (65%). The mean diurnal range (bio2) between 6.7°C-7.5°C displayed favourable likelihood of occurrence. The highest value (0.65) of probability was observed at 7.1°C and beyond 7.5°C it fell. About 50 percent stable likelihood was observed at an isothermality (bio3) range of 6.25-6.65. The bio3 range of 6.9-7.1 was most favourable for the distribution of the bird with the highest (90%) stable possibility. The probability of presence of the bird was the maximum (63%) at 9.5°C temperature seasonality (bio4). Later the chance decreased and at 12.5°C of bio4, increased to 50 percent. At 34°C of the maximum temperature of warmest month (bio5) the probability of existence of bird was the maximum (65%) and the chance decreased with the increase in bio5. Between 22°C-25°C of the minimum temperature of the coldest month (bio6) the distribution of the bird was expanding. At 22.5°C of bio6 the probability of occurrence was 77% and then it decreased to a stable value of 0.63 between 23.5°C-24.3°C. The possibility of appearance of the bird was the maximum (0.64) at 10.5°C temperature annual range (bio7). Between 13°C-14°C the probability decreased a lot and then increased beyond 15°C. The distribution of the bird was greater between 26°C-27°C of the mean temperature of wettest quarter (bio8). At 26.5°C the likelihood of existence was the maximum (62%). From 26°C of the mean temperature of driest quarter (bio9) the distribution rate increased. The maximum probability (75%) was exhibited at 28.5°C of bio9. Then the probability decreased to a stable value beyond 29°C. The distribution of the Greater-spotted Eagle was fair between 28°C-30°C of the mean temperature of warmest quarter (bio10). Highest likelihood (69%) value was observed at 29.4°C of bio10. For the presence of the bird the mean temperature of coldest quarter (bio11) between 26°C-27°C was favourable. The annual precipitation (bio12) >2700mm and <3500mm contributed to the occurrence of the bird. With 60% probability there was appearance of the bird at 3300mm. The likelihood of existence was 50 percent when the precipitation of wettest month (bio13) >500mm and <1000mm. At 700mm the chance was 60%. The precipitation of driest month (bio14) below 5mm was highly favourable for the bird with 75% probability. But beyond 2mm the rate decreased to 30%. Between 24mm-25mm there was a small increase in likelihood to 47%. The precipitation seasonality (bio15) ranging from 80mm-120mm had somewhat stable probability (50-55%) for the occurrence of the bird. Beyond 120mm the probability decreased. At 1700mm of the precipitation of the wettest quarter (bio16) the probability of occurrence was 60%. Then it declined to 50% at 2500mm and thereafter continuously declined. The favourable values of the precipitation of driest quarter (bio17) for bird's distribution were 16mm and 114mm with 70% and 68% probabilities respectively. In between the possibility was less except at 39mm (50%). The maximum probability (60%) was observed when the precipitation of warmest quarter (bio18) became 550mm. In between 400mm and 650mm 50 percent was the chance and beyond 700mm it decreased. For negligible value of the precipitation of coldest quarter (bio19) the likelihood of appearance was high (80%). With 1mm increase the probability suddenly declined and increased to 60% at 1900mm.

The annual mean temperature (bio1) from 28°C-29°C was favourable for the distribution of the Isabelline Wheatear with a stable 60% probability. The chance had increased with increase in bio1. Between 5.5°C-6°C of the mean diurnal range (bio2) the possibility of appearance was high (74%). Beyond 6°C the chance was negative.

Isothermality (bio3) range from 6.9-7.2 was favourable for the bird's occurrence with the maximum stable possibility. Generally the probability increased with increase in bio3. With 61% probability, temperature seasonality (bio4) from 7.5-8.5 was good for the bird's distribution. The rate of distribution lowered with increased temperature seasonality. The increment in the maximum temperature of warmest month (bio5) ascended the probability of distribution of the Isabelline Wheatear. The maximum stable probability (53%) was observed between 37°C-39°C. The possibility of occurrence increased with the elevation in the minimum temperature of coldest month (bio6). A stable value of probability (67%) was observed between 22°C-24.5°C. The temperature annual range (bio7) was suitable for the bird's existence with 72% probability. Beyond 9°C the chance descended with ascend in bio7. The likelihood of existence of the bird was the maximum (75%) between 28°C-30°C of the mean temperature of wettest quarter (bio8). Generally bio8 greater than 26°C was found suitable for the bird's distribution. As the mean temperature of driest quarter (bio9) increased the possibility of appearance also ascended. Between 29°C-31°C the maximum likelihood of 0.65 was noted. The ascend in the mean temperature of warmest quarter (bio10) increased the probability of distribution as the greatest value (60%) was exhibited between 30°C-32°C. A consistent 64% possibility was found between 27°C-28.5°C of the mean temperature of coldest quarter (bio11). Above 50% probability was exhibited when the annual precipitation (bio12) ascended beyond 3000mm. Between 6000mm-7000mm possibility was the maximum (60%). The likelihood of existence was 50-51% as the precipitation of wettest month (bio13) increased from 700mm-2500mm. When the precipitation of driest month (bio14) ranged between 14mm-40mm the distribution of the species was fair. A stable 52.4% chance was displayed between 37mm-42mm of bio14. The maximum likelihood of occurrence (51%) was exhibited when the precipitation seasonality (bio15) range from 4mm-5mm. With the increase in precipitation seasonality the possibility decreased. The favourable value of the precipitation of wettest quarter (bio16) was above 1800mm. The likelihood was the highest (55%) between 4800mm-5300mm. The precipitation of driest quarter (bio17) between 70mm-160mm exhibited 50-51% possibility. When bio17 >140mm and <160mm there was maximum probability (51%). The presence of the bird was confirmed between 900mm-1000mm of the precipitation of warmest quarter (bio18). Bio18 >400mm was favourable for the distribution of the bird. When the precipitation of coldest quarter (bio19) varied from 4000mm-4500mm a stable probability of 0.57 was displayed. A likelihood greater than 50 percent was observed when bio19 >1500mm and <4500mm.

5.3 CURRENT AND FUTURE PREDICTIONS OF THE DISTRIBUTION OF THE SELECTED MIGRATORY BIRD SPECIES

5.3.1 Current distribution

Using the MaxEnt model and 19 environmental variables, the current distribution patterns of the selected migratory birds in Kerala were found. The presence records of the birds were used for modelling purpose. According to Jose (2016) the most abundant distribution of the Indian Peafowl was observed in the central part of Kerala, especially in Palakkad and Thrissur districts.

The distribution pattern for the Black-headed Bunting in Kerala depicted in Fig.6. revealed that in the low lands of Thiruvananthapuram, Kannur and Kasargode districts the bird distribution was high with a probability of 0.69. Also some sort of abundance was found in the lowlands of Thrissur, Kollam, Malappuram and Kozhikode districts having a probability greater than 50 percent. The Black-headed Bunting is a scare passage migrant which migrates to India from Israel in autumn, found in open scrubs from semi-desert to sub-alpine meadows. In the northern and central parts of the country it is a summer breeding visitor primarily in Rajasthan, Uttar Pradesh, Madhya Pradesh, Gujarat, Maharashtra and Karnataka extending south to northern Karnataka and western Tamilnadu (Srivastava, 2014). Unfamiliar to the condition, the Punchakkari wetlands in Thiruvananthapuram and the Kattampally wetlands in Kannur had recent spotting of the Black-headed Bunting (usually prefer dry areas) according to the bird watchers and they are in a suspicion that it is an indication of dry spell in Kerala (Anon., 2009). In the modelling of the Black-headed Bunting distribution in Kerala the mean diurnal temperature (bio2) showed higher percent contribution of 38.2% followed by the minimum temperature of the coldest month (bio6) 26.8%. Moreover the permutation importance and jack-knife analysis of the variables revealed that bio2 and bio6 are controlling the distribution rate of the Black-headed Bunting in the present condition and would be in the future also. When the mean diurnal range (bio6) was 5.5°C-6°C the probability of presence of the bird was sure with 80% probability. Likewise with 60% possibility it appeared as the minimum temperature of coldest month (bio6) ranged from 14°C-23°C. The table.1 included in the appendix-1 shows that at Changaram wetlands in Alappuzha the bird was spotted when bio6measured 22.4°C. The values of bio6 were 21.9°C, 21.8°C and 21.9°C at Munderikkadavu, Payyambalam and

Pulloopi Kadavu respectively. In the Punchakkari wetlands at Thiruvananthapuram the presence of the bird was observed when bio6 was 22.6°C. The table. 7 in the appendix-2 showed the variations in the mean diurnal range (bio2) at different regions in Kerala. In Alappuzha and Kannur districts bio2 was around 7°C while a slight decrease was observed in Thiruvananthapuram (6°C). The increase in the precipitation of driest quarter (bio 17) caused the decrease in the arrival of the species. So for the existence of the Black-headed Bunting warmer temperatures are essential and this could indicate the drier condition prevailing and upcoming in the state.

The current distribution pattern depicted in Fig.20. showed the abundance of the Bluethroat in the midlands of Thrissur with a probability of 0.92. Also the presence was observed on some parts of high lands of Palakkad, low lands of Thiruvananthapuram and low lands of Alappuzha. There were presences of the Bluethroat with a probability greater than 50 percent in the low lands of Kannur, Kasargode, Alappuzha and Thrissur. The Bluethroat is a small passerine bird sighted usually in the open dry spaces. The breeding grounds of the bird are Alaska and Europe but migrate to dry hotter regions of Iran and Gulf countries. In India they are usually spotted in the state of Rajasthan, Andhra Pradesh and dry regions of North India. In the past few years they were spotted in the Punchakkari wetlands, Kavassery, Palakkad and Kole wetlands of Thrissur in Kerala. According to the bird watchers this could be an indication of the climate change in Kerala usually leading to a harsh summer (Anon., 2011). According to the MaxEnt model the distribution of the Bluethroat was favoured by the bioclimatic variables, minimum temperature of coldest month (bio6) and mean temperature of driest quarter (bio9) with percent contributions 49.7 and 26.5 respectively. The variable annual mean temperature (bio1) also had some contribution while evaluating the permutation importance and jack-knife analysis. The favourable minimum temperature of coldest month (bio6) for the occurrence of the bird was between 22°C-24°C with around 70% possibility. When the mean temperature of driest quarter (bio9) was in the range of 29°C-31°C, 80% was the probability of presence of the bird. The value of bio1 preferred was 27.5°C and with the increase in bio1 the species occurrence likelihood decreased. During the time of arrival of the Bluethroat bio6 varied from 21.7°C-22.6°C and bio9 ranged from 26.6°C-28.8°C in the districts of Kollam, Kannur, Palakkad, Alappuzha, Thrissur and Thiruvananthapuram.

The distribution pattern for the given bird in Kerala is depicted in Fig. 34. Mainly in the low lands of Thiruvananthapuram, with the probability of 0.85 the presence of bird was noted. There was also distribution of Gray-headed Lapwing in the low lands of Kollam and

Alappuzha, the low lands and mid lands of Thrissur district with a probability greater than 50 percent.The Gray-headed lapwing is a lapwing species which breeds in northeast China and Japan. In northern Southeast Asia from India to Cambodia the mainland population of this species winters. These birds were found in the north western and eastern parts of India. The Gray-headed Lapwings were believed to be rare winter visitors in Kerala. But since 1999, many reports of this dry weather bird have been recorded from various areas of Kerala reported the presence in Kerala. After carrying out the modelling process using MaxEnt it could be found that the contribution given by the variables minimum temperature of coldest month (bio6) and mean temperature of driest quarter (bio9) were the greatest regarding the distribution of the bird in Kerala.The minimum temperature of the coldest month (bio6) showed high percent contribution of 70 followed by the mean temperature of the driest quarter (bio9) and the temperature annual range (bio7) with decreased percentage values of 6.8 and 6.6 respectively. Bio6 had the maximum contribution in the context of permutation importance and jack-knife analysis. Here other than bio9 small contributions were given by the mean temperature of wettest quarter (bio8), mean diurnal range (bio2) and temperature annual range (bio7). From the meteorological data shown in table. 3 (Appendix-1) the observation was that the value of bio6 ranged from 21.8°C-22.6°C in the northern, central and some of the southern districts of Kerala except Trivandrum (25.5°C). Likewise bio9 varied from 26.6°C -28.3°C in the different districts.

The current distribution pattern depicted in Fig. 48. showed the abundance of the Stonechat in the low lands of Kannur (above 90%). Also the presence was observed on some parts of mid lands of Thrissur, low lands and mid lands of Alappuzha with a probability of 0.77. There were presences of the Stonechat in the low lands of Thiruvananthapuram and high lands of Palakkad near the Palakkad gap. The Stonechat is a common breeding resident in Europe, Asia and Africa, seen in the waterless areas of Trans-Caspian and Trans-Aral deserts. The habitat types are marsh areas, moors, deciduous forests and open pasture lands. The wintering range of the migratory bird is from southern Japan south to Thailand and India and west to north-east Africa. In Kerala the sighting of the Stonechat in the recent years at the Punchakkari wetlands was analysed as an indication of upcoming severe drought by the ornithologists. For the significant increase in the distribution of the bird in Kerala, major contribution was given by the variables, precipitation of driest quarter (bio17) and minimum temperature of coldest month (bio6) with values 30.5 and 21 respectively. The permutation importance and jack-knife analysis confirmed that bio17 had the greater role in the distribution of the species followed by the precipitation seasonality (bio15), mean diurnal range (bio2) and precipitation of driest quarter (bio17). When bio17 measured 15mm, the likelihood of presence of the bird was the maximum (85%). The meteorological data given in the table. 12 showed that bio17 ranged from 8mm-114mm in the different districts of Kerala at the period of arrival of the bird. In Kasargode and Kannur was the value of bio17 lowest while the highest value was observed at Kottayam, Ernakulam and Alappuzha. Bio6 ranged from 21.5°C-22.6°C with the lowest values at Kannur, Kasargode and Kottayam and highest value at Thiruvananthapuram.

The current distribution pattern of the Greater-spotted eagle depicted in Fig. 62. showed the occurrence of the Greater-spotted Eagle in the central regions of Kerala with a probability of 0.92. Also the presence had increased to the low lands of Thrissur and some parts of low lands of Kannur. The spread was observed to the low lands of Alappuzha and mid lands of Alappuzha and Kottayam. Greater-spotted eagle occurs in forested areas and wetlands including temperate and boreal forests, temperate shrub lands and sub-tropical and tropical mangrove forests. It breeds from eastern Europe to Siberia and China and winters in southern Europe, southern Asia, the Middle East and Africa. Outside the breeding season also it occurs in more open and drier habitat. In India this species winters widely, especially in the northern parts and there are a few records from Tamil Nadu, Karnataka, Andhra Pradesh and Goa. As per the birdwatchers the Greater-spotted Eagle was spotted in Kattampally (Kannur), Punchakkari (Thiruvananthapuram) and Kole wetlands of Thrissur. For the distribution of the Greater-spotted Eagle in Kerala significant contribution was given by the bioclimatic variables mean temperature of the coldest month (bio6) and precipitation of the coldest quarter (bio19) with respective percent values of 45 and 15. By analysing the permutation importance and jack-knife tests it was clear that bio6 was the major variable contributing the distribution of the bird in Kerala. At 22.5°C of bio6 the probability of occurrence was 77% in the state. For negligible value of the precipitation of coldest quarter (bio19) the likelihood of appearance was high (80%).The climate data shown in appendix-1 revealed that bio19 ranged from 90mm-284mm (table. 11) in the various districts of Kerala whereas bio6 from 15.8°C-22.6°C (table. 6) respectively. For bio6 and bio19 least values were obtained at Wayanad. The highest value of bio6 was at Thiruvananthapuram followed by Alappuzha and that of bio19 was at Idukki followed by Thiruvananthapuram and Kollam.

The current distribution pattern depicted in Fig. 76. showed the occurrence of the Isabelline Wheatear over the entire plains of Kerala excepting the high lands of Wayanad, Palakkad, Idukki and Kollam. The distribution range was not much stronger as the probability ranged between 50-60 percent. The Isabelline Wheatear is a migratory species with an eastern Palearctic breeding range extending from Southern Russia, the Caspian region, the Kyzyl Kum Desert and Mongolia to Afghanistan, Iran, Iraq, Saudi Arabia, Syria, Jordan and Israel with wintering regions in Africa and north-western India. It is found in the open country, barren tracts of land, arid and semi-arid regions, steppes, sandy grounds and the borders of cultivated lands. They were spotted at the eastern slopes of the Western Ghats, drier areas of the Konkan, Goa, and the Deccan Plateau in Andhra Pradesh, Raichur district in Karnataka, Kannur and Kottayam districts in Kerala. In the case of the Isabelline Wheatear, the mean temperature of the coldest month (bio6) showed a high percent contribution of about 70.7 followed by bio2 but a very least value than bio6. The permutation importance and jack-knife test evaluation also had stated bio6 as the remarkable variable in the appearance of the bird in Kerala. The possibility of occurrence increased with the elevation in the minimum temperature of coldest month (bio6). A stable value of probability (67%) was observed between 22°C-24.5°C.Between 5.5°C-6°C of the mean diurnal range (bio2) the possibility of appearance was high (74%). The table. 2 in the appendix-1 displayed the range of bio6 in the districts of Ernakulam, Kannur, Thiruvananthapuram and Alappuzha with the values 22.3°C, 21.7°C, 22.6°C and 22.4°C while that of bio2 with the values 7.6°C, 7.2°C, 6°C and 7°C.

5.3.2 Predicted future distributions

The predicted future distribution of the selected migratory birds viz. the Black-headed Bunting, the Bluethroat, the Gray-headed Lapwing, the Stonechat, the Greater-spotted Eagle and the Isabelline Wheatear in Kerala were shown in the figures (7-14), (21-28), (35-42), (49-56), (63-70) and (77-84) respectively. The predictions were obtained from the models created using the nineteen bioclimatic variables under four different Representative Concentration Pathways (RCP) such as RCP2.6, RCP4.5, RCP6.0 and RCP8.5 in Kerala for the years 2050 and 2070. There would be expansion in the distribution of the migratory birds compared to the present one.

The change in the environmental conditions would be favourable for the increase in spread in the future. Eventhough the study deals with the environmental parameters (bioclimatic variables) the arrival of these birds in the present and near present made it helpful for their future predictions. Hence by analysing the habitat and climatic variables favourable for the given birds, the study was conducted. Generally these birds inhabit dry regions and their current distribution in Kerala is due to the increment in atmospheric temperature and decrease in precipitation. So there would be expansion in the distribution with the alteration in the climatic factors.

From the MaxEnt model the future projections for each bird were obtained for the respective RCPs in 2050 and 2070 in Kerala. Generally for all the given migratory birds the projection was such that there would be expansion in the distribution along the entire plains of Kerala excepting the highlands of Idukki and Wayanad. But there would be expansion of the distribution of the Greater-spotted Eagle and the Stonechat towards the highlands of Idukki and Wayanad. The projections obtained from the four different RCPs for each of the birds displayed stronger abundance in the entire state of Kerala. The variations in temperature and precipitation from the present situation that would occur in the future would be the reason for abundant distribution. The presence of the birds would extend towards the low lands, mid lands and high lands of Thiruvananthapuram, Kollam, Pathanamthitta, Thrissur, Ernakulam, Malappuram, Kozhikode, Kannur and Kasargode, low lands and mid lands of Alappuzha, mid lands and high lands of Kottayam and Palakkad. There would be stronger abundance especially in the highlands and mid lands of Palakkad due to the presence of the Palakkad gap. The bioclimatic variable mean temperature of the coldest month (bio6) had a common contribution for the distribution of all birds. Along with bio6, mean diurnal range (bio2),mean temperature of driest quarter (bio9), precipitation of driest quarter (bio17) and precipitation of coldest quarter (bio19) contributed the distribution of the Black-headed Bunting and the Isabelline Wheatear, the Bluethroat and the Gray-headed Lapwing, the Stonechat, the Greater-spotted Eagle respectively.

The meteorological data of the different RCPs are given within the tables in Appendix-1. There would be increase in the atmospheric temperature in 2050 and 2070 as per the values of the bioclimatic variables generated under the four different RCPs. For the Black-headed Bunting, the values of bio6 under RCP2.6 would alter from 22.9°C-23.6°C, RCP4.5 (23.7°C-24.5°C), RCP6.0 (23.3°C-24.2°C), and RCP8.5 (23.9°C-24.9°C) in the year 2050 in the districts of Alappuzha, Kannur and Thiruvananthapuram. Similarly in 2070 bio6 values under RCP2.6 would vary from22.8°C-23.3°C, RCP4.5 from 24.6°C-25.4, RCP6.0 from 23.9°C- 24.8°C and RCP8.5 from 25°C-26.1°C. Considering the future distribution of the Black-headed Bunting, in the districts of Alappuzha, Kannur and Thiruvananthapuram the variation in bio2 under the RCP2.6 would be from 5.7°C-7°C, RCP4.5 would be from 5.8°C-

7.1°C, RCP6.0 from 5.7°C-7.1°C and RCP8.5 from 5.6°C-7°C in 2050. In the year 2070 the value of bio2 under RCP2.6 would change from 5.8°C-7.2°C, RCP4.5 from 5.7°C-7.1°C, RCP6.0 from 5.5°C-6.9°C and RCP8.5 from 5.4°C-6.8°C.

In the case of the Bluethroat, in 2050 the values of bio6 under RCP2.6 would range from 22.8°C-23.6°C, RCP4.5 from 23.6°C-24.4°C, RCP6.0 from 23.2°C-24.3°C and RCP8.5 from 23.8°C-25°C over the entire plains of Kerala. Bio6 values in 2070 under RCP2.6 would alter from 22.2°C-23.3°C, RCP4.5 from 24.5°C-25.5°C, RCP6.0 from 23.9°C-24.9°C and RCP8.5 from 25°C-26.4°C. Likewise bio9 under RCP2.6 would vary from 27.6°C-28.6°C, RCP4.5 from 28.8°C-30.7°C, RCP6.0 from 28.2°C-30.2°C and RCP8.5 from 28.9°C-31°C in 2050. The value of bio9 in 2070 under RCP2.6 would fluctuate from 27°C-28.6°C, RCP4.5 from 29.2°C-31.3°C, RCP6.0 from 28.8°C-30.8°C and RCP8.5 from 30.1°C-32.3°C.

For the Gray-headed Lapwing, in 2050 the value of bio6 under RCP2.6 would range from 22.9°C-23.7°C, RCP4.5 from 23.7°C-24.5°C, RCP6.0 from 23.9°C-24.4°C and RCP8.5 from 24°C-25.1°C. The bio6 values under RCP2.6 would be varying from 22.8°C-23.4°C, RCP4.5 from 24.6°C-25.6°C, RCP6.0 from 23.9°C-24.9°C and RCP8.5 from 24.9°C-26.4°C in 2070. Bio9 values for the year 2050 under RCP2.6 would be changing from 27.6°C-28.6°C, RCP4.5 from 28.7°C-31°C, RCP6.0 from 28.2°C-29.6°C and RCP8.5 from 28.8°C-30.3°C. In 2070 the values of bio9 would fluctuate from 27°C-28.4°C, 29.2°C-30.6°C, 28.8°C-30.2°C and 29.9°C-31.4°C under RCPs 2.6, 4.5, 6.0 and 8.5 respectively.

For the distribution of the Stonechat, the values of bio6 would be changing from 22.5°C-23.6°C, 23.4°C-24.5°C, 23°C-25.3°C and 23.5°C-25°C respectively under the RCPs 2.6, 4.5, 6.0 and 8.5 in 2050. For the year 2070 bio6 would range from 22.5°C-23.3°C, 24.3°C-25.4°C, 23.6°C-24.8°C and 24.6°C-26.2°C under RCPs 2.6, 4.5, 6.0 and 8.5 respectively. For the year 2050, the values of bio17 under RCP2.6 would range from 8mm-106mm, RCP4.5 from 8mm-103mm, RCP6.0 from 8mm-114mm and RCP8.5 from 8mm-101mm. In 2070 the values of bio17 under RCP2.6 would range from 8mm-73mm, RCP4.5 from 9mm-132mm, RCP6.0 from 8mm-98mm and RCP8.5 from 11mm-123mm.

In the case of the Greater-spotted Eagle, in 2050 the values of bio6 would vary from 17.1°C-23.7°C, 17.8°C-24.5°C, 17.6°C-24.3°C and 18.7°C-25°C under RCPs 2.6, 4.5, 6.0 and 8.5 respectively. For the year 2070, bio6 would vary under RCP2.6 from 16.4°C-23.4°C, RCP4.5 from 19°C-25.5°C, RCP6.0 from 18.4°C-24.9°C and RCP8.5 from 20.3°C-26.3°C. Bio19 for the year 2050 would differ from134mm-383mm, 117mm-333mm, 110mm-727mm and 128mm-956mm under the respective RCPs 2.6, 4.5, 6.0 and 8.5 respectively. In 2070 bio19 under RCP2.6 would vary from 122mm-329mm, RCP4.5 from 100mm-842mm, RCP6.0 from 127mm-855mm and RCP8.5 from 124mm-977mm.

Considering the distribution of Isabelline Wheatear the values of bio6 would vary under RCP2.6 from 22.8°C-23.6°C, RCP4.5 from 23.6°C-24.5°C, RCP6.0 from 23.2°C-24.2°C and RCP8.5 from 23.8°C-24.9°C in 2050. Bio6 values range from 22.7°C-23.3°C, 24.7°C-25.4°C, 24°C-24.8°C and 25.2°C-26.2°C under RCPs 2.6, 4.5, 6.0 and 8.5 respectively. Likewise in250, bio2 values would fluctuate from 5.7°C-7.1°C, 5.8°C-7.4°C, 5.7°C-7.2°C and 5.6°C-7.1°C under the RCPs 2.6,4.5,6.0 and 8.5 respectively. The value of bio2 under RCP2.6 would range from 5.8°C-7.3°C, 5.7°C-7.3°C, 5.5°C-7°C and 5.4°C-6.8°C.

CHAPTER-6

SUMMARY AND CONCLUSION

The change in the climatic conditions seriously affects species habitat by forcing them to either shift their habitat to suitable regions conducive to their existence and they need to migrate at different rates through fragmented landscapes. These migrations can be considered as a biological indicator of climate change as these species are expected to track the shifting climate. Regarding the distribution of the species temperature and precipitation regimes have a major role. Avian species are one of the best bioindicators and many migrating birds are very sensitive to environmental changes and are already being affected by climate change.

For analyzing the distribution of different species, environmental niche modeling (ENM) or species distribution modelling (SDM) could be done. The best suited niche model used is maximum entropy based model i.e., MaxEnt. This predictive niche model provided very good results for modelling the bird species distribution for present conditions as well as prediction for future scenarios. Using these SDMs it is able to identify the potential places of their occurrences and helpful in executing conservation steps to protect them in the changed habitat.

The present research was focused on the impacts of climate change on the temporal and spatial distribution of the selected migratory bird species in Kerala. Using modelling techniques, the distribution for the same is projected for the years 2050 and 2070 under various climate change scenarios. The occurrence data for the birds till 2016 was collected from e-Bird. Using the current climatic conditions (1950-2000) obtained from WorldClim as bioclimatic layers; current distribution was done using the MaxEnt software by Maximum Entropy method. To carry out the modelling process for the future prediction of distribution of these bird species, the same current bioclimatic layers along with the future bioclimatic layers for different RCPs such as RCP2.6, RCP 4.5, RCP 6.0 and RCP 8.5 were utilized.

By analyzing the current and projected future distribution, following results have been obtained.

- In determining the distribution of the selected migratory bird species using MaxEnt, cross-validation was done for the migratory birds viz. the Black-headed Bunting and the Isabelline Wheatear while subsampling for the Bluethroat, the Gray-headed Lapwing, the Stonechat and the Greater-spotted Eagle for current modelling and future projections.

- The bioclimatic variable mean temperature of the coldest month (bio6) had a common contribution for the distribution of all birds. Along with bio6, mean diurnal range (bio2),mean temperature of driest quarter (bio9), precipitation of driest quarter (bio17) and precipitation of coldest quarter (bio19) contributed greatly to the distribution of the Black-headed Bunting and the Isabelline Wheatear, the Bluethroat and the Gray-headed Lapwing, the Stonechat, the Greater-spotted Eagle respectively.
- Except for the Black-headed Bunting and the Stonechat species, all other species have the highest percent contribution and permutation importance from the variable bio6 itself.
- The percent contribution and permutation importance from bio2 was greater than that from bio6 in the model for the Black-headed Bunting.
- For the Stonechat species highest percent contribution was from bio17 than bio6. But the permutation importance by bio15 was much greater than bio 17.
- Analysing the percent contribution, permutation importance and jack-knife test for the model of the given bird species it is evident that the variable bio6 has an indispensable role in the distribution of the selected migratory birds considered in the study.
- Along with bio6, bio2 and bio17 play a significant role in the distribution of the Black-headed Bunting and the Stonechat species respectively.
- The response curves from the MaxEnt output with logistic prediction changes as each environmental variable has varied, keeping all other environmental variables at their average sample value and those obtained when the corresponding variable is only used, showed different probability ranges for each of the bird species.
- The distribution pattern for the Black-headed Bunting in Kerala revealed that in the low lands of Thiruvananthapuram, Kannur and Kasargode districts the bird distribution was high with a probability of 0.69.
- The current distribution pattern of the Bluethroat showed the abundance of the bird in the midlands of Thrissur with a probability of 0.92 followed by some parts of high lands of Palakkad, low lands of Thiruvananthapuram and low lands of Alappuzha.
- The distribution pattern for the Gray-headed Lapwing in Kerala noted the presence of the bird mainly in the low lands of Thiruvananthapuram, with a probability of 0.85 followed by the low lands of Kollam and Alappuzha, the low lands and mid lands of Thrissur with a probability greater than 50 percent.

- The current distribution pattern showed the abundance of the Stonechat in the low lands of Kannur (above 90%) followed by some parts of mid lands of Thrissur, low lands and mid lands of Alappuzha with a probability of 0.77.
- The current distribution pattern of the Greater-spotted eagle showed the occurrence of the Greater-spotted Eagle in the central regions of Kerala with a probability of 0.92 followed by the low lands of Thrissur and some parts of low lands of Kannur.
- The current distribution pattern showed the occurrence of the Isabelline Wheatear over the entire plains of Kerala excepting the high lands of Wayanad, Palakkad, Idukki and Kollam and the distribution range was not much stronger as the probability ranged between 50-60 percent.
- Prediction of all the given migratory species in the year 2050 and 2070 for all four different RCP values showed maximum range expansion from the current distribution to overall plains of entire Kerala excepting the highlands of Idukki and Wayanad.
- Towards the highlands of Idukki and Wayanad, there would be expansion of the distribution of the Greater-spotted Eagle and the Stonechat
- The prediction in range expansion of these three migratory birds needs more serious further investigation due to its importance in the conservation and management aspects and the results may also help to invite the serious attention of scientific community on the issues related to climatic changes in the future

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APPENDIX

Sl. No	Place	1950-2000	2050				2070			
			RCP 2.6	RCP 4.5	RCP 6	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6	RCP 8.5
1	Changaram wetlands,Alappuzha	22.4	23.5	24.3	24.1	24.8	23.2	25.3	24.7	26.1
2	Munderikkadavu, Kannur	21.9	23	23.8	23.4	24	22.8	24.7	24	25.2
3	Payyambalam, Kannur	21.8	22.9	23.7	23.3	23.9	22.8	24.6	23.9	25.1
4	Pulloopi Kadavu, Kannur	21.9	23	23.8	23.4	24	22.8	24.6	23.9	25
5	Punchakkari fields, Thiruvananthapuram	22.6	23.6	24.5	24.2	24.9	23.3	25.4	24.8	26.1

Table. 1. Minimum temperature of coldest month (bio6) in °C– **Black-headed Bunting**

Sl. No	Place	1950-2000	2050				2070			
			RCP 2.6	RCP 4.5	RCP6	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6	RCP 8.5
1	Nedumbassery, Ernakulam	22.3	23.4	24.2	24.1	24.8	23	25.3	24.6	26.2
2	Elayavoor, Kannur	21.7	22.8	23.6	23.2	23.8	22.7	24.7	24	25.2
3	Punchakkari fields, Thiruvananthapuram	22.6	23.6	24.5	24.2	24.9	23.3	25.4	24.8	26.1
4	Changaram Wetlands, Alappuzha	22.4	23.5	24.3	24.1	24.8	23.2	25.3	24.7	26.1

Table. 2. Minimum temperature of coldest month (bio6) in °C– **Isabelline Wheatear**

Sl. No	Place	1950 - 2000	2050				2070			
			RCP 2.6	RCP 4.5	RCP 6	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6	RCP 8.5
1	Pallipad, Alappuzha	22.6	23.7	24.5	24.4	25	23.4	25.5	24.9	26.3
2	Koovappadi, Ernakulam	22.3	23.4	24.2	24.1	24.9	23	25.3	24.6	26.3
3	Near Chithrapuzha, Ernakulam	22.2	23.3	24.1	24	24.7	23	25.2	24.5	26
4	Polachira Bund, Kollam	22.6	23.7	24.5	24.4	25.1	23.3	25.6	25	26.4
5	Munderikkadavu, Kannur	21.9	23	23.8	23.4	24	22.8	24.7	24	25.2
6	Pilicode, Kannur	21.8	22.9	23.7	23.2	23.8	22.9	24.6	23.9	24.9
7	Perumthuruth, Kottayam	22.5	23.6	24.4	24.3	25	23.3	25.5	24.8	26.3
8	Puthuppally, Kottayam	22.5	23.6	24.4	24.3	25	23.3	25.5	24.8	26.3
9	Ponnani lake, Malappuram	22.3	23.4	24.1	23.9	24.7	23	25.1	24.5	26.1
10	Karingalichal lake, Alappuzha	22.5	23.6	24.4	24.3	25	23.2	25.5	24.9	26.3
11	Punnayurkulam, Thrissur	22.4	23.5	24.2	24	24.9	23.1	25.3	24.6	26.3
12	Muriyad, Thrissur	22.2	23.3	24.1	23.9	24.8	22.9	25.2	24.5	26.2
13	Vadakkekad,Thrissur	22.3	23.4	24.1	23.9	24.7	23	25.1	24.5	26.1
14	Punchakkari fields, Thiruvananthapuram	22.6	23.6	24.5	24.2	24.9	23.3	25.4	24.8	26.1
15	Akkulam, Thiruvananthapuram	25.5	23.5	24.4	24.2	24.9	23.2	25.4	24.8	26

Table. 3. Minimum temperature of coldest month (bio6) in ^{o}C– **Gray-headed Lapwing**

Sl. No	Place	1950 - 2000	2050				2070			
			RCP 2.6	RCP 4.5	RCP 6	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6	RCP 8.5
1	Polachira bund,Kollam	22.4	23.5	24.3	24.1	24.8	23.2	25.3	24.7	26.1
2	Munderikkadavu, Kannur	22.4	23.5	24.3	24.1	24.8	23.2	25.3	24.7	26.1
3	Vayalapra park, Kannur	21.9	23	23.8	23.3	23.9	22.9	24.6	24	25
4	Malampuzha Dam, Palakkad	21.7	22.9	23.6	23.6	24.7	22.2	24.9	24.1	26.4
5	Karingalichal lake, Alappuzha	22.5	23.6	24.4	24.3	25	23.2	25.5	24.9	26.3
6	Parakkad, Thrissur	22.4	23.5	24.2	24	24.9	23.1	25.3	24.6	26.3
7	Koorkenchery, Thrissur	22.4	23.5	24.3	24.1	24.9	23.1	25.3	24.6	26.3
8	Arimpur,Thrissur	22.4	23.5	24.2	24	24.9	23.1	25.3	24.6	26.3
9	Kaduppassery, Thrissur	22.4	23.5	24.3	24.1	25	23.1	25.4	24.7	26.4
10	Punchakkari fields, Thiruvananthapuram	22.6	23.6	24.5	24.2	24.9	23.3	25.4	24.8	26.1
11	Pullu,Thrissur	22.3	23.4	24.1	23.9	24.8	23	25.2	24.5	26.1
12	Valapattanam river, Kannur	21.7	22.8	23.6	23.2	23.8	22.7	24.5	23.9	25

Table. 4. Minimum temperature of coldest month (bio6) in °C– **Bluethroat**

Sl. No	Place	1950 - 2000	2050				2070			
			RCP 2.6	RCP 4.5	RCP 6	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6	RCP 8.5
1	Changaram wetlands, Alappuzha	22.4	23.5	24.3	24.1	24.8	23.2	25.3	24.7	26.1
2	Nedumbassery, Ernakulam	22.3	23.4	24.2	24.1	24.8	23	25.3	24.6	26.2
3	Chellanam, Ernakulam	22.3	23.4	24.2	24	24.7	23.1	25.2	24.6	26
4	Valluvan Kadavu,Kannur	21.9	23	23.8	23.4	24	22.9	24.7	24	25.2
5	Munderikkadavu, Kannur	21.8	22.9	23.7	25.3	24	22.8	24.6	24	25.2
6	Kanayi, Kannur	21.5	22.6	23.4	23	23.6	22.5	24.3	23.6	24.7
7	Panayal,Kasargode	21.5	22.5	23.5	23	23.5	22.6	24.3	23.6	24.6
8	Paravanthuruth, Kottayam	22.5	23.6	24.4	24.3	25	23.3	25.5	24.8	26.3
9	Cherapuram,Kannur	21.8	23	23.7	23.4	24.2	22.7	24.7	24.1	25.5
10	Irimbiliyam, Malappuram	22.2	23.4	24	23.8	24.7	22.9	25.1	24.4	26.2
11	Adatt,Thrissur	22.3	23.4	24.1	23.9	24.8	23	25.2	24.5	26.2
12	Kovalam, Thiruvananthapuram	22.6	23.6	24.5	24.2	24.9	23.3	25.4	24.8	26.1
13	Muthanga, Wayanad	21.8	23	23.7	23.4	24.2	22.7	24.7	24.1	25.5
14	Pazhayangadi, Kannur	21.6	22.7	23.5	23.1	23.7	22.6	24.4	23.7	24.8

Table. 5. Minimum temperature of coldest month (bio6) in °C– **Stonechat**

Sl. No	Place	1950 - 2000	2050				2070			
			RCP 2.6	**RCP 4.5**	**RCP 6**	**RCP 8.5**	**RCP 2.6**	**RCP 4.5**	**RCP 6**	**RCP 8.5**
1	Padanilam,Alappuzha	22.5	23.6	24.4	24.3	25	23.2	25.5	24.9	26.3
2	Purakkadu, Alappuzha	22.6	23.7	24.5	24.3	25	23.4	25.5	24.9	26.2
3	Kuthirakoor Kari, Ernakulam	22.2	23.3	24.1	23.9	24.6	23	25.1	24.5	25.9
4	Mullaperiyar Reservoir, Idukki	17	18	19	19	19.7	17.7	20.2	19.5	21.2
5	Polachira Bund, Kollam	22.4	23.5	24.3	24.1	24.8	23.2	25.3	24.7	26.1
6	Munderikkadavu, Kannur	21.8	22.9	23.7	23.3	24	22.8	24.6	24	25.2
7	Elayavoor, Kannur	21.7	22.8	23.6	23.2	23.8	22.7	24.7	24	25.2
8	Vellikkeel EcoTourism Park, Kannur	21.9	23	23.8	23.4	23.9	22.7	24.6	24	25.1
9	Kallara, Kottayam99	22.5	23.6	24.4	24.3	25	23.3	25.5	24.8	26.3
10	Puthupally, Kottayam	22.5	23.6	24.4	24.3	25	23.3	25.5	24.8	26.3
11	Kakkur, Kozhikode	21.1	22.3	23	22.7	23.5	19	24	23.3	24.9
12	Ponnani lake, Malappuram	22.3	23.4	24.1	23.9	24.7	23	25.1	24.5	26.1
13	Punchakkari fields, Thiruvananthapuram	22.6	23.6	24.5	24.2	24.9	23.3	25.4	24.8	26.1
14	Chethalayam waterfalls,Wayanad	15.8	17.1	17.8	17.6	18.7	16.4	19	18.4	20.3
15	Adatt, Thrissur	22.3	23.4	24.1	23.9	24.8	23	25.2	24.5	26.1

Table. 6. Minimum temperature of coldest month (bio6) in °C– **Greater-spotted Eagle**

Sl. No	Place	1950 - 2000	2050				2070			
			RCP 2.6	**RCP 4.5**	**RCP 6**	**RCP 8.5**	**RCP 2.6**	**RCP 4.5**	**RCP 6**	**RCP 8.5**
1	Changaram wetlands,Alappuzha	7	6.6	6.8	6.7	6.6	6.8	6.8	6.5	6.4
02	Munderikkadavu, Kannur	7.3	7	7.1	7.1	7	7.2	7.1	6.9	6.8
3	Payyambalam, Kannur	7.1	6.8	7	7	6.8	7	7	6.8	6.6
4	Pulloopi Kadavu, Kannur	7.2	6.9	7.1	7.1	6.9	7.1	7.1	6.9	6.8
5	Punchakkari fields, Thiruvananthapuram	6	5.7	5.8	5.7	5.6	5.8	5.7	5.5	5.4

Table. 7. Mean diurnal range (bio2) in °C – **Black-headed Bunting**

Sl. No	Place	1950 - 2000	2050				2070			
			RCP 2.6	RCP 4.5	RCP 6	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6	RCP 8.5
1	Nedumbassery, Ernakulam	7.6	7.1	7.4	7.2	7.1	7.3	7.3	7	6.8
2	Elayavoor, Kannur	7.2	6.9	7	7	6.9	7.1	7	6.9	6.7
3	Punchakkari fields, Thiruvananthapuram	6	5.7	5.8	5.7	5.6	5.8	5.7	5.5	5.4
4	Changaram Wetlands, Alappuzha	7	6.6	6.8	6.7	6.6	6.8	6.8	6.5	6.4

Table. 8. Mean diurnal range (bio2) in °C – **Isabelline Wheatear**

Sl. No	Place	1950 - 2000	2050				2070			
			RCP 2.6	RCP 4.5	RCP 6	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6	RCP 8.5
1	Polachira bund,Kollam	26.6	27.6	29.2	28.6	29.3	27.5	29.2	29.2	30.2
2	Munderikkadavu, Kannur	27.7	28.6	29.5	28.9	29.5	28.6	30.1	29.5	30.3
3	Vayalapra park, Kannur	27.6	28.5	29.3	28.7	29.3	28.5	29.9	29.3	30.1
4	Malampuzha Dam, Palakkad	28.8	29.8	30.7	30.2	31	28.3	31.3	30.8	32.3
5	Karingalichal lake, Alappuzha	26.9	27.9	29.5	29	29.6	27.8	29.5	29.6	30.6
6	Parakkad, Thrissur	28.4	28.6	30.2	29.7	30.4	28.5	30.8	30.3	31.5
7	Koorkenchery, Thrissur	28.4	28.6	30.2	29.7	30.4	28.5	30.8	30.3	31.5
8	Arimpur,Thrissur	28.4	28.6	30.2	29.7	30.4	28.5	30.8	30.3	31.5
9	Kaduppassery, Thrissur	28.3	28.6	30.1	29.7	30.3	28.4	30.1	30.2	31.4
10	Punchakkari fields, Thiruvananthapuram	27	28	28.8	28.2	28.9	27	29.4	28.8	30.6
11	Pullu,Thrissur	28.4	28.6	30.2	29.7	30.4	28.4	30.8	30.3	31.4
12	Valapattanam river, Kannur	27.5	28.5	29.3	28.7	29.3	28.5	30	29.3	30.2

Table. 9. Mean temperature of the driest quarter (bio9) in °C – **Bluethroat**

Sl. No	Place	1950 - 2000	2050				2070			
			RCP 2.6	RCP 4.5	RCP 6	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6	RCP 8.5
1	Pallipad, Alappuzha	27.6	28	29.5	29	29.6	28	30	29.6	30.6
2	Koovappadi, Ernakulam	27.4	28.4	30	28.9	30.2	28.2	30	30.1	31.2
3	Near Chithrapuzha, Ernakulam	27.2	28.2	29.7	28.7	29.8	28.1	29.8	29.8	30.8
4	Polachira Bund, Kollam	26.6	27.6	29.2	28.6	29.3	27.5	29.2	29.2	30.2
5	Munderikkadavu, Kannur	27.7	28.6	29.5	28.8	29.5	28.6	30	29.3	30.2
6	Pilicode, Kannur	27.4	28.4	29.2	28.5	29.2	28.4	29.8	29.2	29.9
7	Perumthuruth, Kottayam	27.3	28.3	29.7	29.2	29.8	28.2	29.8	29.8	30.8
8	Puthuppally, Kottayam	27.3	28.2	29.7	29.2	29.8	28.1	29.8	29.8	30.8
9	Ponnani lake, Malappuram	28.2	29.2	30	29.5	30.2	28.3	30.6	30.1	31.2
10	Karingalichal lake, Alappuzha	26.9	27.9	29.4	28.9	29.6	27.8	29.5	29.5	30.5
11	Punnayurkulam, Thrissur	28.2	28.5	30	29.5	30.2	28.3	30.6	30.1	31.3
12	Muriyad, Thrissur	28.3	28.5	31	29.6	30.3	28.3	30.1	30.2	31.4
13	Vadakkekad,Thrissur	28.1	28.4	29.9	29.4	30.1	28.2	30.5	30	31.2
14	Punchakkari fields, Thiruvananthapuram	27	28	28.8	28.2	28.9	27	29.4	28.8	30.6
15	Akkulam, Thiruvananthapuram	26.9	27.9	28.7	28.2	28.8	27	29.3	28.8	30.5

Table. 10. Mean temperature of the driest quarter (bio9) in °C – **Gray-headed Lapwing**

Sl. No	Place	1950-2000	2050				2070			
			RCP 2.6	**RCP 4.5**	**RCP6**	**RCP 8.5**	**RCP 2.6**	**RCP 4.5**	**RCP6**	**RCP 8.5**
1	Padanilam,Alappuzha	103	134	118	110	128	130	112	127	148
2	Purakkadu, Alappuzha	158	147	130	120	140	143	124	138	132
3	Kuthirakoor Kari, Ernakulam	137	165	143	133	155	160	139	153	141
4	Mullaperiyar Reservoir, Idukki	284	383	333	349	401	309	324	399	413
5	Polachira Bund, Kollam	279	378	316	727	956	329	842	855	977
6	Munderikkadavu, Kannur	185	195	177	160	194	191	177	187	177
7	Elayavoor, Kannur	184	193	175	157	190	189	175	184	173
8	Vellikkeel EcoTourism Park, Kannur	190	200	183	165	204	190	186	196	187
9	Kallara, Kottayam	135	164	140	133	156	159	137	153	142
10	Puthupally, Kottayam	125	153	131	125	145	148	127	143	152
11	Kakkur, Kozhikode	182	195	178	158	187	189	173	181	167
12	Ponnani lake, Malappuram	177	193	135	162	139	144	130	136	124
13	Punchakkari fields, Thiruvananthapuram	281	373	289	315	372	325	325	385	892
14	Chethalayam waterfalls,Wayanad	90	186	117	143	137	122	100	169	161
15	Adatt, Thrissur	189	208	148	175	165	207	144	152	138

Table. 11. Precipitation of the coldest quarter (bio19) in mm– **Greater-spotted Eagle**

Sl. No	Place	1950 - 2000	2050				2070			
			RCP 2.6	RCP 4.5	RCP 6	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6	RCP 8.5
1	Changaram wetlands, Alappuzha	111	103	96	109	96	73	132	92	120
2	Nedumbassery, Ernakulam	62	61	58	64	58	39	68	59	67
3	Chellanam, Ernakulam	107	100	92	105	92	70	125	90	115
4	Valluvan Kadavu,Kannur	12	14	11	12	11	11	13	12	18
5	Munderikkadavu, Kannur	13	16	11	13	11	11	14	13	19
6	Kanayi, Kannur	12	14	12	13	11	11	14	12	18
7	Panayal,Kasargode	8	8	8	8	8	8	9	8	11
8	Paravanthuruth, Kottayam	114	106	103	114	101	72	131	98	123
9	Cherapuram,Kannur	25	30	21	23	22	22	26	22	27
10	Irimbiliyam, Malappuram	32	41	27	31	26	24	35	29	30
11	Adatt,Thrissur	37	45	30	36	30	27	40	32	34
12	Kovalam, Thiruvananthapuram	86	81	61	75	69	58	101	60	82
13	Muthanga, Wayanad	22	23	16	19	19	18	23	19	22
14	Pazhayangadi, Kannur	11	13	10	12	9	10	13	11	17

Table. 12. Precipitation of the driest quarter (bio17) in mm– **Stonechat**

IMPACT OF CLIMATE CHANGE ON THE TEMPORAL AND SPATIAL DISTRIBUTION OF THE SELECTED MIGRATORY BIRDSPECIES IN KERALA

by

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THESIS ABSTRACT

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ABSTRACT

Global warming and climate change are terms for the observed century scale rise in the average temperature of the earth's climate system and its related effects. The climate change prior to industrial revolution can be explained by natural phenomena. Anthropogenic climate change has a significant role on physical and biological systems all over the globe. The multiple components of climate change are anticipated to affect all the levels of biodiversity, from organism to biome levels. Researches have been done in identifying the factors affecting species distribution and analysing their current and future distribution pattern. Species are affected in a different manner, many are forced to migrate at different rates through fragmented landscapes. The migration of animals and birds is linked to climate factors such as temperature, moisture availability and amount of daylight. These migrations can be considered as a biological indicator of climate change as these species are expected to track the shifting climate. Avian species are one of the best bioindicators and many migrating birds are very sensitive to environmental changes and are already being affected by climate change. Increasing temperatures, changing vegetation and extreme weather conditions lead to significant changes of the birds' essential habitats. The present study is a supporting element for the above statements. The spatial and temporal distribution of selected migratory species was studied in identifying the changing climate. Certain dry land inhabiting bird species such as Bunting species (Black-headed Bunting), Lapwing species (Gray-headed Lapwing), Wheatear species (Isabelline Wheatear), Bluethroat, Aquila species (Greater-spotted Eagle) and Stonechat species (Common Stonechat) are selected for the study. Recently the Kerala state has been witnessing the increased number in the arrival of certain migratory birds usually inhabiting the drier tracts of warmer countries.It is hypothesised in the study that the increased distribution of these birds could be an indication that the climate in Kerala is changing. For analysing the species distribution, Maxent model was used. Using the current bird data collected from e-bird database and the climate data acquired from the WorldClim v1.4 database, the modelling for the present condition was done. Then utilising the current distribution analysis, it would project the distribution of the bird species into the future by converging it to the maximum entropy probability distribution.

The study revealed the current (1950-2015) and projected distribution pattern of the selected migratory bird species for the years 2050 and 2070 under different RCP projections.

The current distribution pattern says that the presence of Black-headed Buntingis observed at the northern and southern tips of Kerala, the Bluethroat at the central region, the Grey-headed Lapwing and the Common Stonechat towards the central and southern portions, the Greater-spotted Eagle at the central and southern regions and the Isabelline Wheatear towards the southern regions. The projected modelling results reveal that the distribution of the selected migratory bird species would be expanding more to the entire plains of the Kerala state excepting majority of the high land regions. For the current and future distribution of the given bird species the effect of temperature is more important comparing to precipitation effects.