CURRENT AND FUTURE POTENTIAL DISTRIBUTION OF SARUS CRANE (*Grus antigone*) IN NEPAL USING ENSEMBLE MODELLING

Submitted by

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Kirtipur, Kathmandu
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DECLARATION

I hereby declare that the work presented in this thesis has been done by myself, and has not been submitted elsewhere for the award of any degree. All sources of information have been specifically acknowledged by reference to the author(s) or institution(s).

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This is to recommend that the thesis entitled "Current and future potential distribution of Sarus Crane (*Grus antigone*) in Nepal using ensemble modelling" has been carried out by Ms. Rashmi Acharya for the partial fulfilment of Master's Degree of Science in Zoology with special paper Ecology and Environment. This is her original work and has been carried out under my supervision. To the best of my knowledge, this thesis work has not been submitted for any other degree in any institutions.

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LETTER OF APPROVAL

On the recommendation of supervisor Associate Professor Dr. Hari Prasad Sharma, this thesis submitted by Rashmi Acharya entitled "Current and future potential distribution of Sarus Crane (*Grus antigone*) in Nepal using ensemble modelling" is approved for the examination and submitted to the Tribhuvan University in partial fulfilment of the requirements for Master's Degree of Science in Zoology with special paper Ecology and Environment.

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CERTIFICATE OF ACCEPTANCE

This thesis work submitted by Ms. Rashmi Acharya entitled "Current and future potential distribution of Sarus Crane (*Grus antigone*) in Nepal using ensemble modelling" has been accepted as a partial fulfilment for the requirements of Master's Degree of Science in Zoology with special paper Ecology and Environment.

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LIST OF ABBREVIATIONS

Abbreviated form	Details of Abbreviation
IUCN	International Union for Conservation of Nature
GPS	Global Positioning System
SDM	Species Distribution Model
QGIS	Quantum Geographic Information System
CEA	Cylindrical Equal Area
SSP	Shared Socio-economic Pathways
VIF	Variance Inflation Factor
AUC	Area Under the Curve
ROC	Receiver Operating Characteristics
GLM	Generalized Linear Model
GAM	Generalized Additive Model
MARS	Multivariate Additive Regression Splines
RF	Random Forest
BRT	Boosted Regression Tree
TSS	True Skill Statistics

ABSTRACT

Climate change have a significant impacts on the geographic distribution and composition of species across time and space, but little is known about how they affect wetland birds. Therefore, this study was conducted to address the impacts of climate change on the distribution of Sarus Crane across Nepal. Species occurrence and nest location data were collected from the field through direct observation. The current and future potential distribution of the species was identified using ensemble modelling. The model predicted approximately 4.52% (6,659 km^2) of total Nepal area under current distribution. The suitable area was predicted mostly in western Nepal. Maximum range expansion was found up to 17.33% (12, 2513 km^2) for the distribution under SSP5-8.5 scenarios for 2090. The range expansion for the distribution of species is expected to occur almost entire lowland and some Siwalik regions of Nepal by the end of century. Also, the presence of nesting site relies heavily on the waterbody and agricultural marshland. The findings of this research suggests that agricultural and wetland areas should be managed properly for the conservation of Sarus Crane in Nepal.

1. INTRODUCTION

1.1. Background

1.1.1. Species Information

The Sarus Crane (*Grus antigone antigone,* Linnaeus, 1758*)* is the tallest flying bird in the world and is among the 15 species of cranes globally. With three recognized subspecies, Indian Sarus Crane (*G. a. antigone*), Eastern Sarus Crane (*G. a. sharpie*) and Australian Sarus Crane (*G. a. gilli*) (Archibald et al. 2003), the former one stands at a height of 152–156 cm (BirdLifeInternational 2016) having wingspan up to 675 mm (Johnsgard 1983). The adult Sarus Crane is characterized by gray feathers with red, naked head, upper neck, and pale red legs that become more vibrant during breeding season. Juveniles, on the other hand, have a distinct yellow-brown head and differ from adults (Johnsgard 1983). The average body weight is 6.8–8 kg (Ali and Ripley 1980). Females are slightly smaller than males in size with average wingspan of males is 619.3 mm while females is 612.5 mm; tarsus of male is 323.1 mm while female is 304.1 mm; and exposed culmen of male is 169.3 mm and female is 161.4 mm (Johnsgard 1983). It is an omnivorous species that seems to consume less vegetarian food and relies heavily on fish when it's accessible. It also feeds on other animals such as crustaceans, frog, lizards, locusts, grasshoppers, water snake, snails and other large insects. Among its vegetarian options are grains found in the remaining stalks of crops such as paddy, wheat, maize, mustard, soybean, chickpea, green pea and millet, tubers and corms of aquatic and marsh plants, young shoots of grasses and cereals and groundnuts pods (Ali and Ripley 1980; Johnsgard 1983; Jha and Mckinley 2014; Singh Tomar et al. 2018).

Sarus Crane are social birds and are seen in pairs or flocks of 40–60 during the breeding season (Suwal 1994). They are well known for their lifelong partnerships with their mate. Such faithful and devoted behavior of birds has become legendary in India that has lead to its protection by locals (Ali and Ripley 1980). The breeding season occurs between July to September and bird builds a large nest using reeds, rushes and straws, usually about 1 m in diameter, on a bund in flooded paddy fields or on an island in a swamp or jheel. The eggs are usually two in numbers, greenish or pinkish-white with brown or purple spots and a bright orange inner membrane, having an average weight of egg is 238 gm. Both male and female birds shares the tasks of nest building, incubation and caring for the young ones, however, male plays an important role in protecting the chicks from predators. The incubation period lasts for 28 days (Baral 1970; Ali and Ripley 1980). It has a life span of 15.6 years (BirdLifeInternational 2016).

The Sarus Crane can be found globally in regions such as the Indian sub-continent, South-East Asia, and Northern Australia (Sundar 2019). In Nepal, it was once widespread in the lowlands but now has mainly been confined to the West of the Narayani river in districts such as Rupandehi, Nawalparasi and Kapilvastu (Suwal 1994). They prefer to live near human settlements and open environments such as wetlands, abundantly irrigated paddy fields, grasslands and river banks due to available of suitable habitat for foraging, roosting, and nesting (Prakash and Verma 2019).

The global population of Sarus Cranes is estimated as 13,000 to 15,000 individuals, with the majority of them (8,000–10,000) residing in India, Nepal and Pakistan. In Cambodia, Laos, and Vietnam, the estimated population is around 800–1000, 500–800 in Myanmar and around 10,000 breeding adults in Australia (BirdLifeInternational 2016). In Nepal, the population is estimated between 450 to 700 (Inskipp et al. 2016). However, the population is declining rapidly due to habitat degradation, conversion of wetlands into agricultural land, ingestion of pesticides, poaching of chicks and eggs for food and medicinal purposes. As a result, the species is listed as “vulnerable” under the IUCN Red List of Threatened Species (BirdLifeInternational 2016).

The occurrence of the species is influenced by various factors such as availability of food (Aryal et al. 2009; Jha and Mckinley 2014), suitable wetlands, adequate paddy fields, irrigated land, types of crops grown (Verma and Prakash 2019), presence of human settlements, level of disturbance from road, tourism and villagers (Pathak 2005), presence of predators (such as jackal, cattle, unfamiliar people) (Raj et al. 2016) and infrastructure development such as housing, industrialization, road construction and dam construction. The agriculture landscape also plays a crucial role in its distribution as it avoids farmland with sugarcane and pigeon pea coupled with non-palatable crops, perhaps due to obstruction in free movements (Jha and Mckinley 2014).

1.1.2. Species Distribution Modelling

Species Distribution Models (SDMs) are widely used method for predicting the potential geographical distribution of species (Elith and Leathwick 2009). They combine information about species occurrences with environmental variables to predict the suitable habitat of a species (Elith et al. 2011). The models are widely used in various fields such as biogeography, conservation, biology and ecology (Elith et al. 2011). It is the numerical tool that help in determining the response of species to a set of environmental variables (Elith and Leathwick 2009). The occurrence data and environmental variables are used to predict the potential suitable habitat of a species (Hirzel et al. 2002). The success of SDMs largely depend on the quality of the surveyed data and the relevance of used environmental variables (Elith and Leathwick 2009). For species distribution modelling, the presence locations of species are referred to as sample points, the geographic region of interest is the distribution space and features are the environmental variables (Phillips et al. 1997). There is now a range of modelling algorithms available for developing SDMs such as generalized linear models, regression trees, and Maxent (Phillips et al. 2006). However, choosing the best algorithm for a particular situation can be challenge for users of SDMs (Elith and Graham 2009).

It has been suggested that one may develop numerous models using different modelling methods and integrate the predictions from these models to provide a more accurate result. This technique is known as ensemble prediction. Ensemble is a popular method among users of SDM due to its wide application (Araújo and New 2007; Hao et al. 2019), and it provide more accurate predictions than individual model (Hao et al. 2019). The accuracy of ensemble method is always depend on the accuracy of the individual models they are based on (Araújo and New 2007). Ensemble model can be used for determining the climatic effect and topographic changes on the species distribution at current and future (Katuwal et al. 2022) and potential distribution of threatened species such as Red Panda (*Ailurus fulgens*) (Kandel et al. 2015)

Modelling of species is necessary to know about their habitat requirements, habitat suitability and in conservation planning of species (Braunisch et al. 2016; Kunwar et al. 2021). Environmental predictors have direct or indirect effects on species. Therefore, species distribution models are empirical model that quantifies species-environment relationships, address species' ecological needs and reflect the effect of predictors on species (Guisan and Thuiller 2005; Guisan and Zimmermann 2000).

Many ecological factors are responsible for distribution of species. Depending on ecological factors like food availability, crops pattern and other seasonal factors, Sarus Crane utilizes a broad range of landscapes (Tomar et al. 2017). They utilize open forestland, wetland, grassland shallow land and agricultural land. They are regarded as a sign of rainfall and healthy wetland ecosystem (Kumar et al. 2017). However, its population is gradually decreasing due to anthropogenic activities, loss and degradation of wetland, poaching and illegal hunting (Meine and Archibald 1996). Therefore, understanding and knowledge of factors that influence the species' occurrence is crucial for monitoring and management plans.

1.1.3. Climate Change

One of the major threats to biodiversity is global warming (Garcia et al. 2014) that has broadly identified with the effect on the species dispersion and community composition (Parmesan and Yohe 2003). Climate change has altered the distribution and breeding behavior of species by changing the timing of seasonal activities like migration, flowering or breeding, which may have an impact on the demography and population dynamics of species and composition (Acharya and Chettri 2012). Such shift in climate can have impact on the availability and distribution of climatically suitable areas for species across space and time (Garcia et al. 2014). As a result, range expansion and contraction of species may occur in suitable climatic conditions that are favored by a species (Garcia et al. 2014).

Climate change had an impact on seasonal home range. Irregularity in rainfall influences the landscape ecology of wetland (Verma and Prakash 2018), which in turn altered the availability of food. In monsoon season, the food are easily available, so Sarus Crane covered least ground for incubation, whereas, in pre-nesting period they migrate to wetland areas for roosting and covered large area as compared to nesting period. Thus, the food supply is more scarce and the home range is large in dry climates (Sundar et al. 2000). The normal or high rainfall improves breeding success of Sarus Crane while decline at low rainfall (Sundar 2009). High temperature and low humidity cause damage to the eggs whereas, monsoon provides relief with rainy weather and also availability of abundant aquatic animals and succulent shoots to feed their growing chicks (Suwal 1994). The effects of prolonged drought was found with declining breeding range of White-naped Crane (*Antigone vipio*) and Red-crowned Cranes (*Grus japonensis*) in Amur River Basin. More changes are excepted in coming future with loss of glaciers leading to wetland loss (Mirande and Harris 2019).

1.2. Objectives

1.2.1. General Objective

The general objective of the study was to identify the current and future potential distribution of Sarus Crane in Nepal.

1.2.2. Specific Objectives

The specific objectives were:

i. To identify the current and future potential distribution of Sarus Crane in Nepal

ii. To assess the factors influencing the nest site selection by Sarus Crane in Nepal.

1.3. Significance of Study

Sarus Crane is the only resident breeding crane found in India and South-east Asia (Sachan and Yadav 2018). The IUCN Red List of Threatened Species has listed Sarus Crane as “vulnerable” species and declining at global level. The major reason behind decreasing its population is due to degradation of wetland habitat, unplanned farming, poaching of egg and chick for food and violation of wildlife rules and regulation (BirdLifeInternational 2016; DNPWC and DoFSC 2021). In addition to this, climate change is considered as a new threats to Nepal’s bird (Karmacharya et al. 2020). Climate change has already an effect on phenology, sea level, frequency of extreme occurrences, and temperature (Bellard et al. 2012). They lead to shifting species abundances and distributions within certain sites along with impact on an availability of resources and ecological services (Karmacharya et al. 2020). Changing hydrology in Terai region is affecting the paddy cultivation and wetland that simultaneously affect the life of Sarus Crane (Sundar 2009). Because Sarus Crane depends on wetlands and agriculture fields for both nesting and foraging (Archibald et al. 2003). During critical stages of their annual cycle, such as nesting and rearing offspring, many crane species primarily depend on wetlands for food, shelter and protection. The availability and condition of wetlands greatly impacts the distribution, migration, and reproductive success of Sarus Cranes. As a result, wetlands are considered the most crucial habitat for these birds, however, they are being negatively impacted by human activities as well as by climate change (Austin et al. 2018; Sundar 2009). Additionally, the presence of Sarus Cranes in not solely determined by the presence of flooded rice fields or irrigated land, but also by other factors such as the type of vegetation at the edge of the crop field, the type of crop grown, and the openness of the habitat. These additional factors play a role in determining the suitability of the environment for the species and thus, its likelihood of occurrence (Prakash et al. 2014). Therefore, this study developed a map of potential suitable habitat and the impacts of climate change in Sarus Crane distribution in Nepal. So that the concerned organizations can use this information for locating and protecting those areas and can provide important nesting grounds during the breeding season and also can protect an important permanent wetlands in dry season.

2. LITERATURE REVIEW

2.1. Global Distribution of Sarus Crane

Sarus Crane is the tallest flying bird and requires broad areas for foraging and breeding. It is the only residential breeding crane that is distributed in Nepal, Australia and Southeast-Asia (Archibald et al. 2003) with an estimated population size of about 13,000-15,000 (BirdLifeInternational 2016). With three recognized subspecies, they are confidently present in Nepal, India, Myanmar, Cambodia, Lao People's Democratic Republic, Vietnam, China, Pakistan and Australia, and became regionally extirpated in Malaysia, Thailand and Philippines (Baral 1970; Archibald et al. 2003; BirdLifeInternational 2016). The Sarus Crane (*G. a. antigone*) has been extirpated from a huge amount of its historic range and is still declining in regions where it still survives (Aryal 2004).

The largest population of the species can be found in Gangetic Plain in Uttar Pradesh, Gujrat, eastern Rajasthan and Haryana (Ali and Ripley 1980, Verma and Prakash 2016). Uttar Pradesh supports the biggest number of Sarus Crane in India (Kumar et al. 2019). In Uttar Pradesh, Etawah and Manipur are the major districts with maximum number of Sarus Cranes (Archibald et al. 2003). In Uttar Pradesh, a total of 11,905 individuals were documented from entire state and was more concentrated in the South and Western districts of state around common Gangetic Plains, Yamuna and Chambal rivers (Jha and Mckinley 2014). Maximum number of population are concentrated along the Gangetic Plain whereas, minimum in Bundelkand region in Uttar Pradesh, India. The reason behind the maximum population is because of maintained water level from Ganga River, which indicate as a favorable habitat for Sarus Crane breeding and foraging. On the other hand, Bundelkand is water scarce area that results in declining number of Sarus Crane (Kumar et al. 2019). A total of 1,902 Sarus Cranes were documented from the 43 districts of Uttar Pradesh from 2008-2017 (Kumar et al. 2019). Also, a comparative analysis in eight consecutive years from 2012-2019 in Alwara Lake of Kaushambi district of Uttar Pradesh documented the increasing trend of Sarus Cranes (Verma and Prakash 2017). And the reason behind its increasing pattern was due to positive efforts, proper management and awareness campaigns (Prakash and Verma 2019) which results in the favorable environmental conditions for Sarus Crane in and around Alwara lake (Verma and

Prakash 2016). In addition, very few population of about 500 were observed from Madhya Pradesh, Maharashtra and Bihar states in central India (Sundar 2019).

2.2. Distribution of Sarus Crane in Nepal

There have been several studies on the population of Sarus Crane in Nepal. They are abundant in Rupandehi and Kapilvastu district, sparsely scattered in western part of the country and most probably extinct from the eastern part of the country (Suwal 1994). There are probably fewer than 450-700 individuals are present in Nepal (Inskipp et al. 2016) and their distribution range was thinning for the last decades (Suwal 1994). The Sarus Crane were observed by using road transect method in Rupandehi and Kapilvastu district of Nepal and found 128 and 131 individuals in Rupandehi and Kapilvastu district during consecutive year 1995 and 1996, respectively (Shrestha 1996). While in 2009, the observed number of Sarus Crane was 168 individuals in Rupandehi and Kapilvastu district with direct observation (Aryal et al. 2009). Such difference in number of individuals might be due to methodology used. Since road transect method considered only accessible roads and missed the other potential areas for Sarus Crane leading to underestimate the actual number of them. Although number of individual had increased but a questionnaire survey with local people conformed that the population of Sarus was declining since last few years (Aryal et al. 2009). Gosai et al. (2016) reported 143 number of individuals in Rupandehi district. In Nawalparasi west, the population of Sarus Crane was recorded from 14 to 18 individual in 2005-2006 (Sharma 2006).

The elevational record for Sarus Crane was from 150-300 m in Nepal (Inskipp et al. 2016). In 2015, the first presence record of Sarus was confirmed as there are no previous presence record in Dang at an altitude of 545 m, the highest record for Sarus in Nepal. There were only two conceivable locations from which the cranes may have arrived in the Dang district given their known range in Nepal: either Banke or Kapilvastu. It's also conceivable that during their journey between Banke and Kapilvastu, cranes may make brief stops in Dang and Banke (Singh 2017; Khanal 2019)

Rupandehi district is the central district where Sarus Crane population concentration is high in comparison to other parts of Nepal. In Rupandehi district, they are distributed in the south-central region of Nepal. They are high around Lumbini area, Jogada, Masina, Marcharbar site, and Kamariya Village. In northern part of the district, the occurrence of Sarus is not documented because it has sal and mixed forest with churia range. In Kapilvastu district, they are highly distributed around Patariya, Lawani, Hatihawa, Bithuwa and Pakadi (Aryal 2004). Also in Nawalparasi west, Sarus Crane have been observed all year in Germi, Sanai, Rampur, and Kudiya regions, while in Sukrauli, Hakui Devgaun, Badera, and Somani they were observed from July to August (Sharma 2006).

2.3. Species Distribution Modelling

Species Distribution Modelling (SDM) is applied to understand the relationships between the species and its environment and to predict suitable part of landscape for species occurrence by creating a map (Elith and Graham 2009). Sometimes SDMs have been term as bioclimatic models, climate envelops, niche models, resource selection function, range maps, and more loosely – correlative or spatial models with different emphases and meanings (Elith and Leathwick 2009). Wildlife conservationist can use SDMs to estimate the global distribution of species. Such models, which are based on database of species and ecosystems, give crucial information on conservation and management requirements for concern species (Guisan and Thuiller 2005; Shengwu et al. 2016). In addition, SDMs has many applications, for instance, in testing bio-geographical, ecological and evolutionary hypothesis (John et al. 1998; Anderson et al. 2002; Raham et al. 2004), for identifying the species invasion (Adhikari et al. 2020) and their proliferation (Beerling et al. 1995), for forecasting potential distribution (Nielsen et al. 2008), potential distribution of threatened species (Kandel et al. 2015; Katuwal et al. 2022), niche overlap (Aryal et al. 2016) and impacts of climate change on the distribution (Brambilla et al. 2022; Katuwal et al. 2022).

The effectiveness of ensemble methods for predicting distribution was evaluated and the accuracy of the prediction was measured by computing the area under the curve of the receiver-operating characteristic plot (Kandel et al. 2015). Based on average function algorithm, the ensemble methods provided more robust predictions compared to the other methods. These findings suggest that ensemble method may significantly improve the accuracy of species distribution forecasts and are promising for various conservation and biological applications (Marmion et al. 2009).

3. MATERIALS AND METHODS

3.1. Study Area

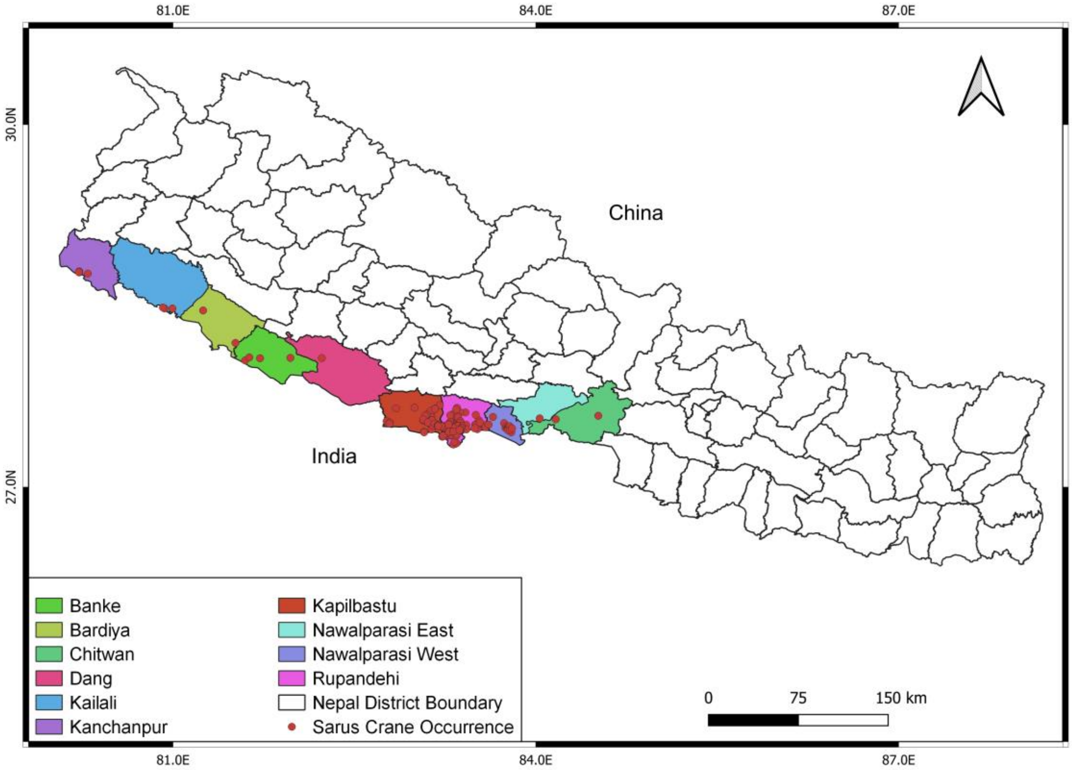

Figure 1: Presence locations of Sarus Crane in Nepal

Nepal is a roughly trapezoidal-shaped landlocked country, lies along the southern slopes of greater Himalayan mountain between China and India within 26.36^o–30.45^o latitude and 80.06^o–88.2^o longitude. Despite making up only 0.09% (147,181 km^2) of the world's land area, it is portrayed as a nation with a high biodiversity, contributing significantly to the world's biodiversity.

Physiographically, Nepal is divided into seven federal provinces, 77 districts and physio graphically into five zones i.e. Tarai (<300 m), Siwalik (300-1,000 m), Mid-hill (1,000-3,000 m), Mid-mountain (3,000-5,000 m) and High mountain (above 5,000 m) (LRMP 1986) as cited by (Sharma et al. 2020).The Terai has a tropical climate and is located in the country's southernmost region along the Nepal-India border from east to west. Siwalik arises abruptly from the Tarai to the North and has a sub-tropical climate. Between Siwalik and High Himal, in the center, lie the Mid Hills and Mountains, which are high, steep, mountainous regions with a temperate climate. The northernmost region of the nation, which borders Tibet, is known as the High Himal zone and has subalpine and alpine climates (Shrestha et al. 2010).

3.1.1. Major Vegetation and Fauna

Nepal's unique geographic location, diverse climatic conditions, complex topography and wide range of habitat support the various biodiversity. It has a diverse range of flora and fauna. It has a high species richness of world's flora and fauna that includes over 6,973 spp. angiosperm; 1,150 spp. bryophytes; 534 spp. pteridophytes; and nearly 26 spp. of gymnosperms. Country also holds high number of faunal species including 212 species of mammals, 892 species of birds, 123 species of reptiles, 55(+-) species of amphibians, 230 species of fish, 3,958 species of moths, 651 species of butterflies and 5,052 species of beetles and other insects (MoFSC 2014; GoN 2022).

3.2. Materials

- GPS Garmin eTrex®10
- Binocular
- Camera
- Measuring tape

3.3. Data Collection

3.3.1. Occurrence of Sarus Crane

Sarus Crane is distributed in the lowlands of western Nepal that features a tropical climate with numerous wetlands. Among the Tarai district, only Kapilvastu, Rupandehi and Nawalparasi have congregated populations of Sarus Crane. The farmlands and wetlands of these district were main area for their breeding. Therefore, Sarus Cranes were searched along the farmlands and wetlands of Rupandehi and Kapilvastu districts (Aryal et al. 2009; Gosai et al. 2016). The occurrence data and nest locations were collected by direct observation using Geographical Positioning System (GPS: Garmin eTrex®10). Field survey was conduct in Nawalparasi, Rupandehi and Kapilvastu districts from August 12 - September 10, 2022 and April 26 - May 4, 2023. The study was carried out during two time periods: the morning between 6:00 AM-12:00 noon and from afternoon to evening between 2:00-6:00 PM as part of regular field trips. A motorcycle was used to travel between survey sites. To accurately determine the presence or absence of Sarus Cranes, the motorcycle speed was maintained at 20-25 km/h, and two people were involved for that observation. Those observation was taken along the road to cover as much accessible area as possible, and the entire periphery was walked to ensure the presence of Sarus Cranes.

A binocular was used for distant vision and local residents' knowledge was taken into consideration to confirm the presence of Sarus Cranes in their vicinity. The locations of Sarus Cranes were recorded, and coordinates was taken by using a hand-held GPS. In addition, the presence location of Sarus Crane were recorded from personal communication with researcher (Hem Bahadur Katuwal: 2010-2015), and only those data which were confirmed with exact locations were used for modelling. Other parameter such as its nesting location was also recorded. The distance of Sarus Crane location was measured using range finder, and later the exact laltitude and longitude of presence location of occurrence was detected using Quantum Geographic Information System (QGIS).

The study survey was coincided with the egg-laying season of the Sarus Cranes. This timing was chosen to minimize pseudo-replication as the birds stayed close to their nests during this period to safeguard the nesting area and eggs. Intensive nest searching was done during the study period moving through the study area on different routes. Observing the movement of bird during survey revealed a sign of nesting, which led us to search for second bird. In majority of cases, the second bird was located nearby taking care of the nest. As the Sarus Crane nest in areas not accessible by ground vehicles, the nest sites were approached on foot. During nest visit, both the location of the nest and the egg were thoroughly examined and photographed. After that, nearest distance from nest location to human settlements, road, water body and agricultural marshland were measured. The nearest distance to these sources was measured using measuring tape, however, the distance >200 m was measured using QGIS. Overall, 175 presence data were collected for the study (Figure 1).

Those data were compiled in a data base with their longitude and latitude. The occurrence data which were in WGS-84 Coordinate Reference System, were converted into equal area cylindrical projections (CEA) also known as Lambert cylindrical equal-area projection with central meridian at 0 degrees longitude and the standard parallel at 30 degrees latitude using 'spTransform' functions in R programme using 'sp' package (Pebesma and Bivand 2005). In the next steps, spatial filtering of species occurrence data was performed in R programme by using 'raster' (Hijmans and Etten 2012) and 'sp' package (Pebesma and Bivand 2005). At first, 'raster' package was used to assign each occurrence point to a cell of 1 km X 1 km raster layer, given that the spatial resolution of bioclimatic variables used in this modelling was 1 km. After that, to prevent the variables used in the modelling from being affected by the proximity of data points, we applied 'sp' package in R program to rarefy the occurrence datasets spatially so that no two points were located within 1 km X 1 km grid (Aiello-Lammens et al. 2015). Following the filtering process, a set of 133 spatially independent presence locations of Sarus Crane were used for modelling.

3.3.1.1. Bioclimatic Variables

The Worldclim database includes annual time series with annual averages, seasonality, and temperature and precipitation extreme or limiting that influence the occurrence of the species (Fick and Hijmans 2017). A total of 19 bioclimatic variables (1970-2000) were downloaded from Worldclim version 2.1 (https://www.worldclim.org/data/bioclim.html) at a resolution of 30 seconds (~1 km^2) to model the current distribution of Sarus Crane in Nepal.

In order to predict impact of future climate changes on the distribution of Sarus Crane in Nepal, the sixth version of the general circulation model, the Model for Interdisciplinary Research on Climatic (MIROC), also known as MIROC6 was downloaded from Worldclim version 2.1. MIRCO6 is a latest version of MIRCO5. MIRCO6 simulates model climatology and internal climate variability more accurately than MIRCO5 (Tatebe et al. 2019). The Intergovernmental Panel on Climate Change developed a series of scenarios called the Shared Socio – economic Pathways (SSPs) that outline anticipated future socioeconomic situations and how they can affect greenhouse gas emissions and climate change. Data are available for four different SSPs for 2050 (2041-2060), 2070 (2061-2080) and 2090 (2081-2100) to account for potential impacts of climate change on the species. All four SSPs were used in the analysis, SSP1-2.6, which is based on a lower emission scenario and projects a mean warming well below 2°C by the end of the century; SSP2-4.5, projects a mean warming well below 3°C; SSP3-7.0, projects mean warming well below 4.1°C and SSP5-8.5, which is based on the highest emission scenario and projects a mean warming of about 5.1°C by the end of this century to cover the full range of projected climate change scenarios (Riahi et al. 2017). The downloaded climatic variables were cropped with a Nepal mask and was converted to CEA projection.

3.3.1.2. Variable Selection

After preparing the bioclimatic layers, Variance Inflation Factor (VIF) was performed in R programme (R Core Team 2022) using ‘sdm’ package (Naimi and Araújo 2016) to avoid multicollinearity in the predictors. The VIF is used to measure multicollinearity when there is a high degree of correlation between predictive variables. It is a more accurate method of determining the strength of each predictors. It is calculated by taking the square of the multiple correlation coefficient (R^2), which is obtained by regressing the predictor variable against all the other predictor variables. A VIF value greater than 10 is considered as model having collinearity problems (Naimi and Araújo 2016). As highly correlated variables leads to model overfitting and by removing highly correlated variables, the model can be simplified leading to more precise and trustworthy predictions of species distribution (Braunisch et al. 2013). In this study, predictors having VIF value greater than 10 were excluded. Finally, out of 19 bioclimatic variables (Appendix 1), only seven bioclimatic variables i.e. Bio 02, Bio 05, Bio 08, Bio 09, Bio 13, Bio 14 and Bio 15 were used in modelling the species distribution across the Nepal (Table 1).

Table 1. Selected bioclimatic variables for the use in Sarus Crane species distribution models and their VIF value.

Predictive Variables	Description	VIF value
Bio 2	Mean Diurnal Range	2.46
Bio 5	Maximum Temperature of Warmest Month	7.35
Bio 8	Mean Temperature of Wettest Quarter	4.86
Bio 9	Mean Temperature of Driest Quarter	7.09
Bio 13	Precipitation of Wettest Month	5.92
Bio 14	Precipitation of Driest Month	7.79
Bio 15	Precipitation Seasonality	4.30

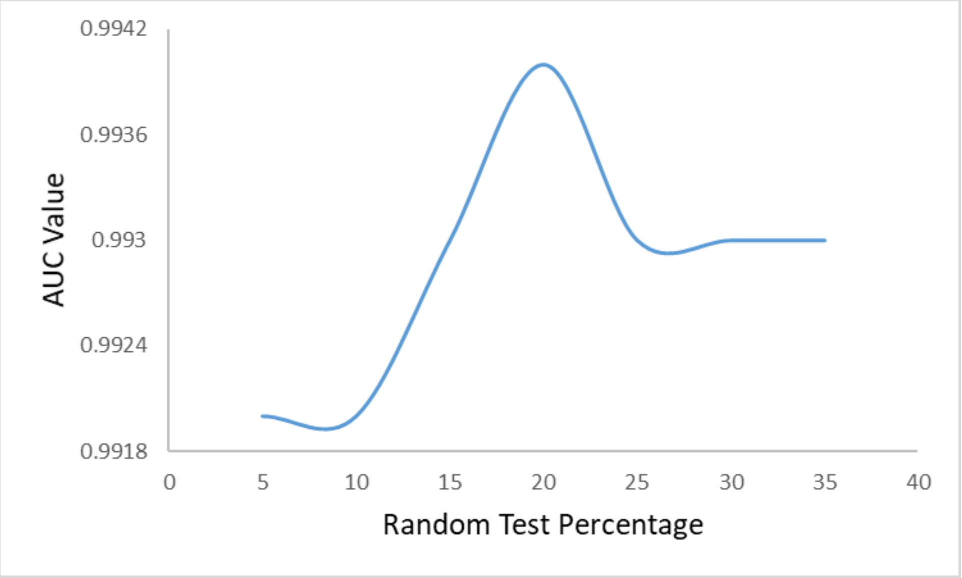

Figure 2: Random test percentage with Area under the Curve Receiver Operating Characteristics.

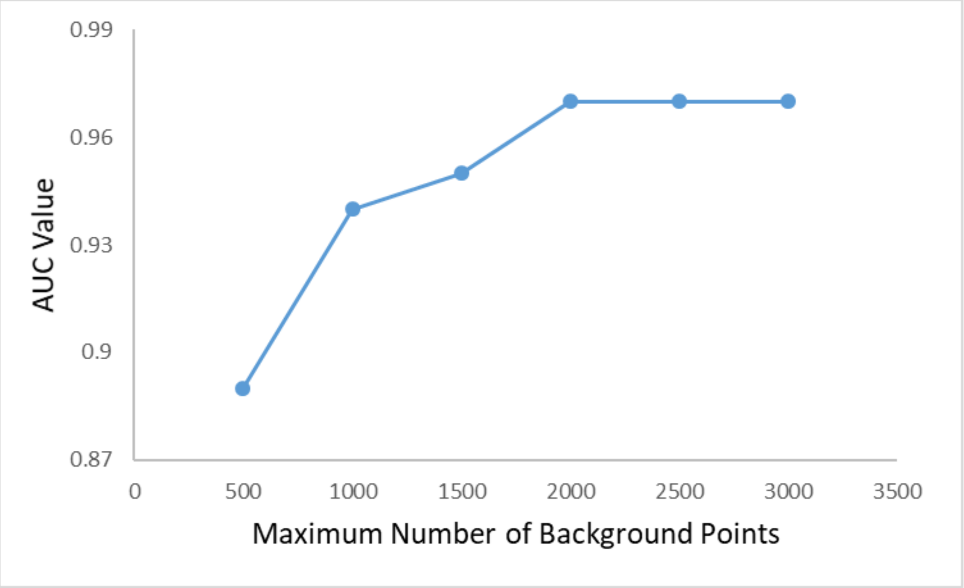

Figure 3: Maximum number of background points with Area under the Curve.

The occurrence datasets was split into two subsets, with 70% used as the training dataset and 30% as the test dataset. The selection of these subsets was based on the area under the curve receiver operating characteristics (AUC) value, which was obtained by evaluating multiple random test percentages (Figure 2).

A total of 2000 background points were selected for the model run, based on a consistent AUC value observed across different background points (Figure 3). Background points are sometimes called pseudo-absences. The goal of the background samples is to offer an accurate representation of the environmental factors available to the species in the modeled region. This is significant because the existence of a species depend not just on its biological traits but also on the environmental factors that allow it to survive and reproduce. By selecting the appropriate background samples, it leads to accurate predictions and a better understanding of the factors that shape the geographic distribution of the species (Phillips et al. 2009).

3.3.2. Methods for Ensemble Modelling

Recent SDM exercises have highly praised the creation of ensemble maps, which combine many models created using different modelling techniques (Hao et al. 2019). Thus, in this study, an ensemble modelling approach was used to develop potential distribution models for Sarus Crane in Nepal. An ensemble models was generated based on five algorithms: Generalized Linear Model (GLM), Generalized Additive Model (GAM), Multivariate Additives Regression Splines (MARS), Random Forest (RF) and Boosted Regression Tree (BRT) by using SDM package (Naimi and Araújo 2016) in R Program (R Core Team 2022). SDM package is an extendable framework that generates ensemble of models, many options for evaluation of model results and projection of species distribution in space and time. It's object – oriented generic nature makes it flexible and suitable for effective error management and provides with graphical user interface that makes it convenient to use (Naimi and Araújo 2016). These five models were constructed by using a random subsets of 70% of the available data. The remaining 30% of the data were used for evaluation of the model's predictive performance. This split-sample process was repeated 10 times, resulting in a total of 50 unique statistical models developed for Sarus Crane. In addition, for replication method, bootstrapping was used because of the low sample size. Since, all these modelling procedure need the information about presence and absence, so pseudo-absence data was created with 2000 background points. The use of the ensemble method was based on the weighted mean approach that improve the accuracy of the final model (Marmion et al. 2009) by maximizing the sum of sensitivity- specificity using True TSS optimization (Naimi and Araújo 2016). This approach convert continuous data into binary data to generate a binary map, also known as presence-absence map. To convert the predicted probabilities into presence and absence, "Maximum Training Sensitivity plus Specificity Logistic Threshold" value was used. After that, area of predicted current and future distribution as well as changes between current and future scenario relative to the area of Nepal was calculated using QGIS.

3.3.3. Model Evaluation and Validation

The accuracy of the model's predictions is examined by the evaluation and validation of SDM using several evaluation statistics such as response curves, variable relevance, and model coefficients. The area under the curve receiver operating characteristics (ROC) curve, also known as the area under the curve (AUC), is a widely employed tool for evaluating the precision of predictive distribution models (Lobo et al. 2008). The ROC plot is generated by plotting sensitivity (true positive fraction) values on the y-axis against their corresponding (1-specificity) values (false positive fraction) for all possible thresholds on the x-axis. The AUC is threshold independent statistics and is considered as significant indicator because it provides a single, overall measure of accuracy that is not reliant on a particular threshold (Fielding and Bell 1997). The AUC value ranges from 0 to +1 and used as an indicator of how well a model is performing, with scores ranging between 1 to 0.9 being excellent, 0.9 to 0.8 indicating good, 0.8 to 0.7 being considered fair, 0.7 to 0.6 representing poor performance and 0.6 to 0.5 being considered a failure (Swets 1988). Due to criticism of the use of AUC for model evaluation (Lobo et al. 2008), True Skill Statistics was used additionally to examine the predictive performance of model. It is a threshold dependent statistics and scores range from +1 to -1, with a score close to 1 indicating an almost perfect model, while score close to 0 or less than 0 indicates that the model is no better than random (Allouche et al. 2006). Although these two approaches are distinct from one another, it is advised to employ them both for cross-checking (Marmion et al. 2009). As a result, in this study TSS was used to assess predictive performance of ensemble model, whereas, AUC and TSS to compare among individual models.

4. RESULTS

4.1. Model Performance and Contribution of Predictor Variables

The ensemble model demonstrated good predictive performance for distribution, with TSS value of 0.99 ± 0.02 and AUC value of 0.99 ± 0.007. The algorithm MARS had the lowest TSS value of 0.94, while RF had the highest TSS value of 0.97. Similarly, RF had a highest AUC value (1) and other algorithm had an AUC value of 0.99. Bioclimatic variables had different contributions to our models. The variables that contributed the most were Mean temperature of wettest quarter (BIO 08), Maximum temperature of warmest month (BIO 05), Precipitation seasonality (BIO 15), Mean temperature of driest quarter (BIO 09) and Mean diurnal range (BIO 02). Mean temperature of wettest quarter (BIO 08 = 49%) had the highest contribution, followed by Maximum temperature of warmest month (BIO 05 = 32%), Precipitation seasonality (BIO 15 = 29%) (28.4%), Mean temperature of driest quarter (BIO 09 = 27%), and Mean diurnal range (BIO 02 = 25%) to our model. The lowest contributing variables to our model were Precipitation of driest month (BIO 14) and Precipitation of wettest month (BIO 13) having contribution of 10% and 5%, respectively.

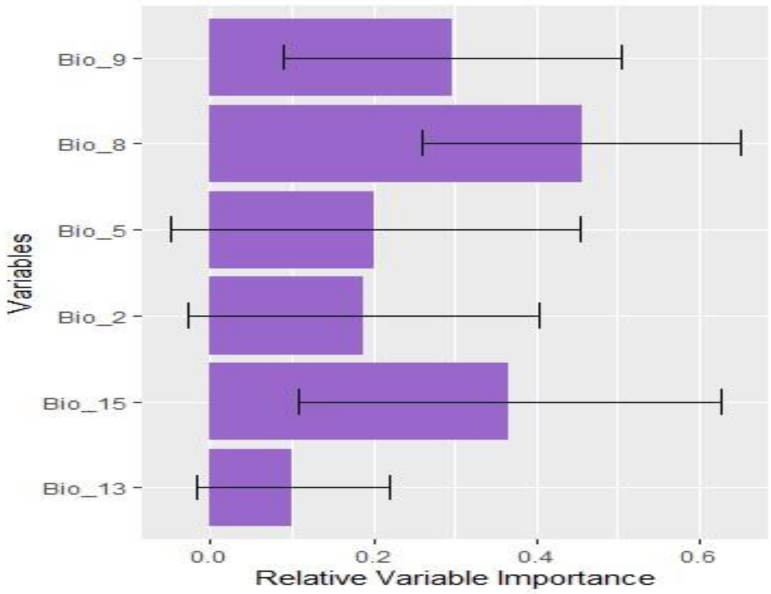

Figure 4: Evaluating the relative contribution of bioclimatic variables in predicting the potential distribution of Sarus Crane in Nepal. Bio_2 refers Mean Diurnal Range, Bio_5 refers Maximum Temperature of Warmest Month, Bio_8 refers Mean Temperature of Wettest Quarter, Bio_9 refers Mean Temperature of Driest Quarter, Bio_13 refers Precipitation of Wettest Month, Bio_14 refers Precipitation od Driest Month and Bio_15 refers Precipitation Seasonality.

4.2. Sarus Crane Distribution

The predicted current distribution of Sarus Crane covers an area of 6,659 km^2 (4.52 %) of total Nepal (Table 2). The most suitable habitat was predicted in western parts of lowland of Nepal i.e. in Banke, Rupandehi, Kapilvastu and Nawalparasi West districts.

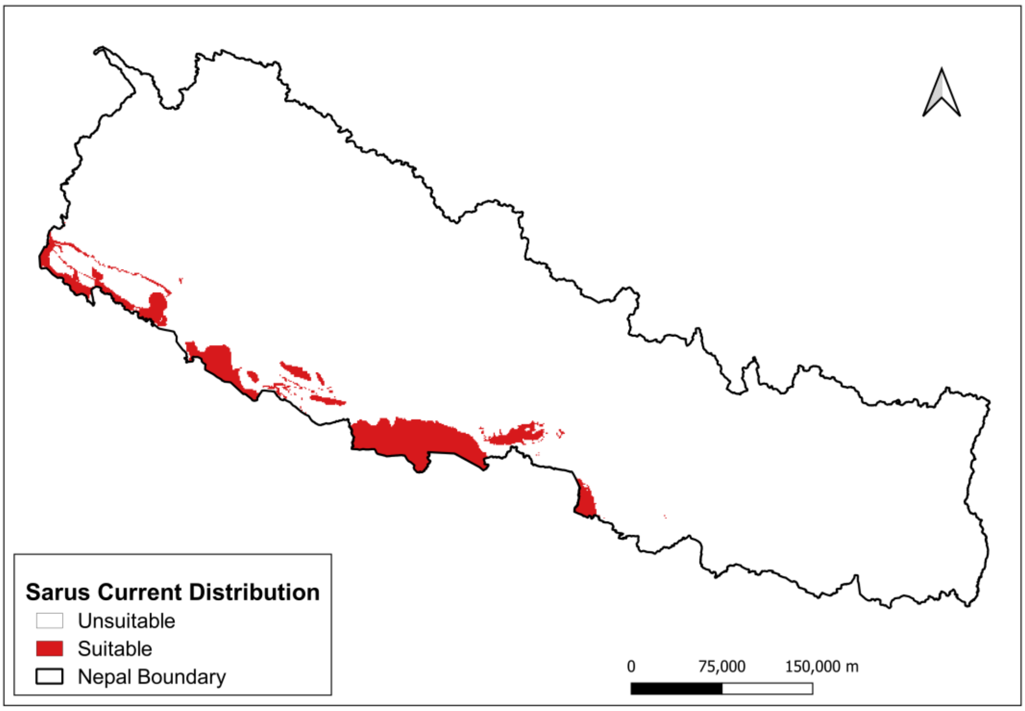

Figure 5: Predicted current distribution range of Sarus Crane in Nepal.

The potential distribution of Sarus Crane was projected to continuously expand with future climate change from its current distribution by the end of century 2100 under SSP1-2.6, SSP 2-4.5, SSP3-7.0 and SSP5-8.5 scenarios. According to the model, the specie's distribution range could expand to a maximum of 17.33 % (25,513 km^2) under SSP5-8.5 scenarios in 2090; whereas, could expand to a minimum of 4.61 % (6,793 km^2) under SSP3-7.0 scenarios in 2050. The model predicted that the range expansion would mostly occur within the existing distribution range and would increase within the almost entire lowland and some siwalik regions of Nepal by the end of century.

Table 2. Estimated area of potential distribution for Sarus crane in Nepal under current and future climate scenario. SSP1-2.6 refers to first scenario, SSP2-4.5 refers to second scenario, SSP3-7.0 refers to third scenario and SSP5-8.5 refers to fourth scenario.

Climate Scenario	Potential distribution area (km^2)		Presence area (%)
	Presence	Absence	
Current	6659	141367	4.52
2050 SSP1-2.6	11230	136796	7.63
2050 SSP2-4.5	9766	138260	6.63
2050 SSP3-7.0	6793	141233	4.61
2050 SSP5-8.5	13117	134909	8.91
2070 SSP1-2.6	13197	134829	8.97
2070 SSP2-4.5	12316	135710	8.37
2070 SSP3-7.0	12400	135626	8.42
2070 SSP5-8.5	16578	131448	11.26
2090 SSP1-2.6	12953	135073	8.80
2090 SSP2-4.5	19748	128278	13.42
2090 SSP3-7.0	11213	136813	7.62
2090 SSP5-8.5	25513	122513	17.33

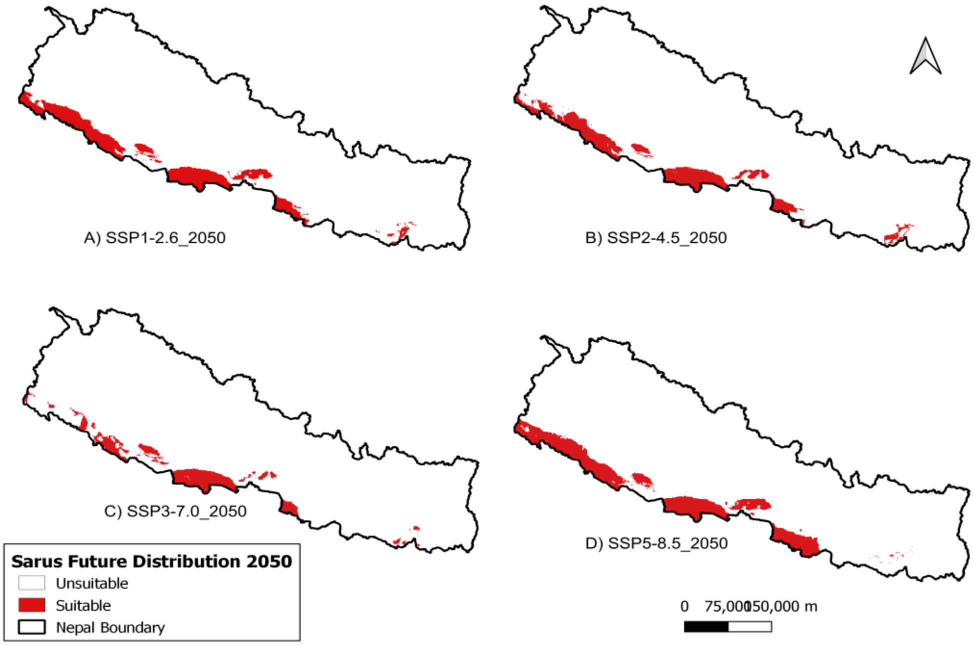

Figure 6: Predicted potential suitable habitat of Sarus Crane in 2050 in Nepal. SSP 1-2.6 refers to first scenario, SSP2-4.5 refers to second scenario, SSP3-7.0 refers to third scenario and SSP5-8.5 refers to fourth scenario.

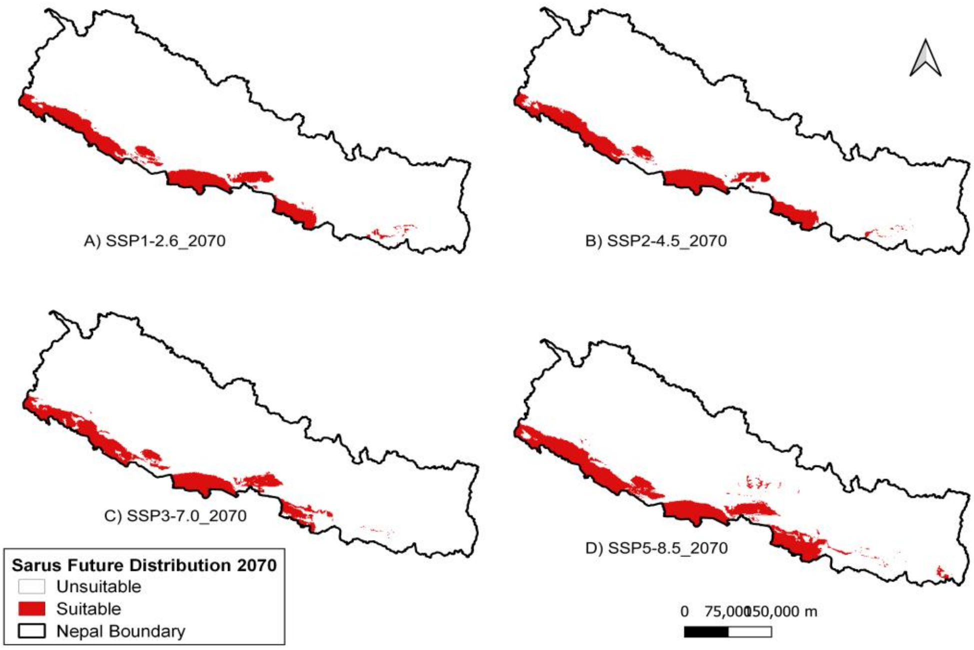

Figure 7: Predicted potential suitable habitat of Sarus Crane in 2070 in Nepal. SSP 1-2.6 refers to first scenario, SSP2-4.5 refers to second scenario, SSP3-7.0 refers to third scenario and SSP5-8.5 refers to fourth scenario.

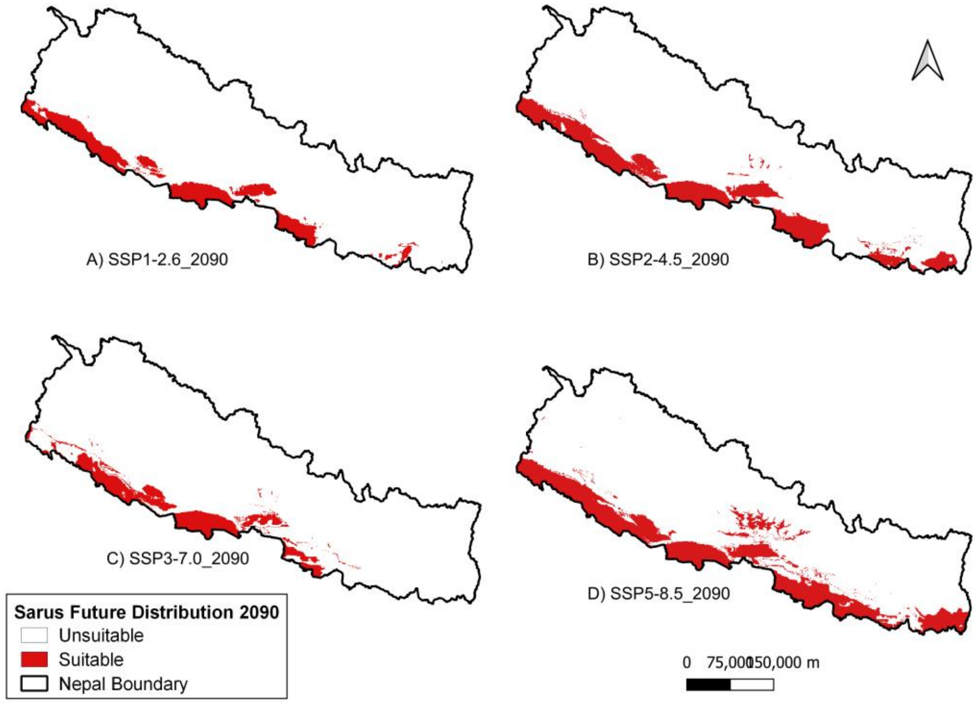

Figure 8: Predicted potential suitable habitat of Sarus Crane in 2090 in Nepal. SSP 1-2.6 refers to first scenario, SSP2-4.5 refers to second scenario, SSP3-7.0 refers to third scenario and SSP5-8.5 refers to fourth scenario.

4.3. Nest Site Presence

A total of 11 nest location of Sarus Crane was recorded during this study. The minimum average distance of nest location to agricultural land was 21.95 ± 245.45 m (SD), and followed by water body 130 ±127.35 m (SD). Whereas, maximum average distance to human settlements was 245.45 ±179.9 m (SD) followed by road 228.28 ± 165.63 m (SD).

5. DISCUSSION

5.1. Model Performance

This study represents the potential distribution of Sarus Crane across Nepal under current and future climates with good model performance in different unbiased model output. Generally, the more accurate forecast can be produced by a pertinent combination of many unbiased model outputs (Marmion et al. 2009; Hao et al. 2019). The accuracy of ensemble is always depends on the accuracy of the single-models on which they are based (Araújo and New 2007). The predictive accuracies of models were assessed by computing TSS. The TSS value of ensemble model were 0.99 which is recognized as an excellent models (Allouche et al. 2006). Furthermore, Weighted mean method provided more robust predictions (Marmion et al. 2009).

5.2. Current Potential Suitable Habitat

In the analysis, most of the current suitable habitats were located in the southern side of western Nepal. The model indicated that the most suitable habitat for Sarus Crane's distribution was in southern lowland (Tarai) Nepal i.e. in Rupandehi and Kapilvastu districts. This study appears to confirm the some of the early findings (Aryal 2004; Gosai et al. 2016). In the previous study, the suitable habitat for Sarus Crane was 868 km^2 and 938.04 km^2 in Rupandehi and Kapilvastu districts, respectively (Aryal et al. 2009). These southern lowlands of Nepal have tropical climatic pattern with abundant wetlands (Katuwal 2016). The majority of their predicted habitat was in lowland because these regions have extensive agricultural land and wetland habitats that are suitable for their foraging and breeding needs, making them a tropical species. Not only Sarus Crane, the other farmland birds such as Lesser Adjutant *Leptoptilos javanicus)* and Asian Open bill *(Anastomus oscitans*) prefers this habitat (Sundar et al. 2018; Katuwal et al. 2022). They prefer open agriculture lands. They spend most of their time by foraging in paddy field, wheat field, fallow lands, ponds, flooded grassland and rarely in flooded forest (Sundar 2009). They avoid forested areas because height of vegetation disrupt the Crane's movement as it has large body size (Jha and Mckinley 2014).

Our model also found that Mean temperature of wettest quarter (BIO 8) and have highest contribution to the distribution of suitable habitat followed by Maximum temperature of warmest month (BIO 5). It represents average temperature during the wettest three month period of the year. The breeding season of Sarus Crane typically occurs between July to September i.e. monsoon period. It has an influence on ecological process such as availability of water and vegetation growth. Sarus Crane is a wetland birds that depend on wetland for foraging and breeding (Kumar and Kanaujia 2017). The rainfall has significant impacts on breeding success of Sarus Crane. Breeding success improves in years with normal or high rainfall whereas, declines with low rainfall because low water level facilitates in the increased predation rates of chicks and eggs (Sundar 2009).

5.3. Future Potential Suitable Habitat

Our model showed that the current distribution of the species are further expected to expand to almost entire lowland and some siwalik regions as well as towards higher elevations in the central regions by the end of the century. These findings suggests that they are likely to be influenced by climate change. However, climate change is a threat to many species (Aryal et al. 2016; Liu et al. 2020; Ansari 2023), still some gets benefit from them (Chhetri et al. 2021; Li et al. 2022). Bird species such as Himalayan pheasants (Chhetri et al. 2021), Lesser adjutant (Katuwal et al. 2022) and Black necked crane (Li et al. 2022) has experienced range expansion whereas, some species such as snow leopard and blue sheep (Aryal et al. 2016), Siberian crane (Ansari 2023), and Red crowned crane (Liu et al. 2020) has experienced range contractions owing to climate change.

The reason for range expansion with climate change because due to global warming and green house emission the temperature will rise that results in glacial melt and increase in sea level. Due to glacial melt, more wetlands will emerge that provide more food resources and habitat for Sarus Crane. In addition to this, continuous warming would reduce the area of permanent glaciers in the mountains (Cui and Graf 2009) and it might be the potential range shift of the species (Khanal 2019) and breeding range (Liu et al. 2020). For instance, Sarus Crane is usually recorded below 300 m but in Dang (Motipur), it was recorded at 545 m which is considered as a highest elevational record till now owing to climate change (Khanal 2019).

In contrast, climate change has resulted in range contraction as well. Climate change results in extreme fluctuations in precipitation levels, including more frequent dry years with fewer rainy days (Mirande and Harris 2019). For instance, the White-naped

Crane and Red- crowned Crane breeding range have been affected by a prolonged drought, influenced by long term climate changes in the Amur River Basin (Mirande and Harris 2019). Also for Black necked Crane, changing precipitation pattern resulted in habitat loss with more drastic changes to be expected in the future with water shortage and extensive loss of wetlands (Mirande and Harris 2019). Climate change might effect in changing species distribution and abundances in individual distribution. In context of India, population is fluctuating within the states i.e. increased in Rajasthan and Uttar Pradesh (Jha and Mckinley 2014), whereas, decreased in Gujrat (Mukherjee et al. 2000). While in context of Nepal, population had increased in Rupandehi and Kapilvastu districts, but decreased from other parts of Nepal. However, the overall as a whole population has increased in Nepal (Katuwal 2016).

Sarus Crane were first reported in 1877 in Nepal (Scully 1879 as cited by Katuwal 2016). They were once distributed in the entire belt lowlands of Nepal from east to west (Baral 2009). The eastern region of southern Nepal lacks presence data. Despite the lacks of presence data from eastern regions of Nepal, model still predicted that region as a potential suitable habitat under future scenarios. It could be because, the area still believed to be important for the species, possibly acting as a viable habitat. If the Sarus Crane was no longer present there, it can be a sign of decline or even loss in that specific part of Nepal (Karmacharya et al. 2020). .

5.4. Nest Site Presence

In this study, the presence of nest was mostly seen near water body and agriculture marshland. It is because Sarus is wetland bird and depends on water for their breeding, fledging and foraging. Sarus Crane’s nest located nearby wetland and agricultural marshland had abundant foods to feed their growing chicks (Sundar 2009). Also, the wetland or marshland around nesting site that were inaccessible experienced low predation and mortality (Kumar and Kanaujia 2017). However, nest located further away from roads and human settlement have higher probability of unsuccessful hatching and experience low egg mortality (Mirande and Harris 2019).

6. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

In this study, under current distribution the south-west lowland regions is likely to have most suitable habitat for Sarus Crane in Nepal. While, distribution is likely to expand in future and may occur in the almost entire lowlands and some siwalik regions of Nepal. Also, the presence of nesting site relies heavily on the water body and agricultural marshland.

6.2. Recommendations

- Detailed scientific study on its ecology and monitoring in existing and new location through telemetry and GIS require further research.
- Further study using of other factors for species distribution modelling using biotic factors such as prey and predator availability and other linear infrastructures for outcomes.

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APPENDIX

Appendix 1: Bioclimatic variables used in Species Distribution Model of Sarus Crane.

Codes	Variables
BIO 01	Annual Mean Temperature
BIO 02	Mean Diurnal Range
BIO 03	Isothermality
BIO 04	Temperature Seasonality (Standard Deviation)
BIO 05	Maximum Temperature of Warmest Month
BIO 06	Minimum Temperature of Coldest Month
BIO 07	Temperature Annual Range
BIO 08	Mean Temperature of Wettest Quarter
BIO 09	Mean Temperature of Driest Quarter
BIO 10	Mean Temperature of Warmest Quarter
BIO 11	Mean Temperature of Coldest Quarter
BIO 12	Annual Precipitation
BIO 13	Precipitation of Wettest Month
BIO 14	Precipitation of Driest Month
BIO 15	Precipitation Seasonality (CV)
BIO 16	Precipitation of Wettest Quarter
BIO 17	Precipitation of Driest Quarter
BIO 18	Precipitation of Warmest Quarter
BIO 19	Precipitation of Coldest Quarter

PHOTO GALLERIES

Picture 1: Sarus Crane nest located in paddy field in Rupandehi.

Picture 2: Sarus Crane standing in the middle of wetland In Lumbini.

Picture 3: Sarus Crane foraging in wetland in Tulsidihawa, Kapilvastu.

Picture 4: Sarus Crane taking flight in Tulsidihawa, Kapilvastu.